Habitat Selection by Parturient and Post-parturient Adult Female Moose (*Alces alces*) on the Canadian Prairies

A Thesis Submitted to the
College of Graduate and Postdoctoral Studies
In Partial Fulfillment of the Requirements
For the Degree of Master of Science
In the Department of Animal and Poultry Science
College of Agriculture and Bioresources
University of Saskatchewan
Saskatoon, SK

By:

Amy Loy Wheeler

Permission to Use

In presenting this thesis in partial fulfilment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor who supervised my thesis work. In the professor's absence, permission may be granted by the Head of the Department or the Dean of the College in which my thesis work was completed. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Disclaimer

Reference in this thesis to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by the University of Saskatchewan. The views and opinions of the author expressed herein do not state or reflect those of the University of Saskatchewan, and shall not be used for advertising or product endorsement purposes.

Requests for permission to copy or to make other use of material in this thesis in whole or part should be addressed to:

Head of the Department of Animal and Poultry Science
51 Campus Drive
University of Saskatchewan
Saskatoon, Saskatchewan S7N 5A8 Canada

OR

Dean
College of Graduate and Postdoctoral Studies
University of Saskatchewan
116 Thorvaldson Building, 110 Science Place
Saskatoon, Saskatchewan S7N 5C9 Canada

Abstract

The expansion of moose into the agricultural landscape of Saskatchewan (i.e., farmland moose) has increased human-wildlife conflicts, raising questions about how to best manage them. To support decision making, I initiated a study on farmland moose reproductive success and habitat selection following parturition (i.e., birth of calves). In 2013 and 2014, adult female moose were captured between Saskatoon and Chamberlain, SK and fitted with Global Positioning System collars. Daily movement rates and clustering of locations were used to determine the date and location of parturition for 27 adult female moose from 2013 to 2015. The mean date of parturition was May 21. Moose were surveyed using Very High Frequency radio telemetry in June and September each year to visually determine the presence and number of calves. Of the pregnant females observed during calf surveys with 1 or 2 calves, twinning rates were 67% (n = 6/9) in June 2013 and 46% (n = 5/11) in June 2014. Habitat selection ratios indicated that wetland and riparian habitat, trees and shrubs, and cropland were selected the most strongly by female moose as parturition habitat, while pastures and forages, developed and native grassland habitat were avoided. Female moose selected parturition sites further away from roads.

A resource selection function model was developed to quantify habitat selection by 15 female moose with young during the first 20 days post-parturition. During this period, adult female moose with young most strongly selected for wetland and riparian areas (β [95% CI] = 0.716 [0.485, 0.946]) and native grassland (β [95% CI] = 0.457 [0.329, 0.585]) and against oilseeds (β [95% CI] = –0.252 [–0.400, –0.103]). Predictive success of the top-ranked model, estimated from *k*-fold cross validation, was r_s = 0.993 (SE = 0.001). The resource selection function indicates that only 10% of the area within the home ranges of parturient females is considered highly selected habitat with high probability of moose use, while 48% of the area has a low probability of use. These results demonstrate the importance of wetland habitat within cropland to female moose, during and shortly after giving birth.

Acknowledgements

I would like to thank my advisor Dr. Ryan K. Brook for providing me this amazing opportunity to study moose in Saskatchewan. I also want to thank Dr. Brook for his professional guidance, encouragement, and understanding during this educational process. I would like to thank the members of my advisory committee, Drs. Natacha S. Hogan, Robert (Bob) G. Clark and Fiona C. Buchanan, for all their input and contributions. I also greatly appreciate the valuable input from my external examiner, Dr. Erin C. McCance.

I will be forever grateful to Michel Laforge and Dr. Nicole Michel for their valuable input and expertise. I would like to specifically acknowledge Rob Tether, the (now retired) provincial moose biologist at the Saskatchewan Ministry of Environment, for his input and support through all aspects of this project. Thank you to Dr. Floris van Beest for valuable comments on my thesis proposal, and to my colleagues within the Wildlife Ecology and Community Engagement Lab: Ruth Kost, Rebecca Kolla, Anja Sorensen, Molly Patterson, Al Arsenault, and Krystal Caldwell, for your help and friendship. I am grateful to the Saskatchewan Fish and Wildlife Development Fund, the Saskatchewan Ministry of Environment, the University of Saskatchewan, the Saskatchewan Wildlife Federation, Cyril Capling Trust at the University of Saskatchewan, and the Natural Sciences and Engineering Research Council of Canada for funding this research.

Several other individuals and companies need to be acknowledged for their contributions to this research. Over 100 additional project volunteers, including Tom Perry, Matthew Walpole, Brittany Arsenault, Murray Gillespie, Raea Gooding, Katherine Conkin, Shelby Adams, Sarah Anderson and Jamie Sparrow, provided considerable logistical support with the study design, obtaining landowner permissions, conducting fieldwork, and obtaining and managing biological samples. Clay Wilson, Mike Reed, Taylor Wilson, and Matt Leuenberger of BigHorn Helicopters conducted the moose capture and collaring work safely and efficiently. Murray Louden and Reed Willison of Mitchinson Flying Service flew the bird dog flights. Prairie Diagnostics Services Inc. determined pregnancy status based on progesterone levels in moose blood samples. The Institute for Wetland and Waterfowl Research shared wetland data that overlapped with my study area. Saskatchewan Government Insurance (SGI) provided moose-vehicle collision data.

I gratefully acknowledge the many landowners who provided permission to capture moose on their property, access to their land when conducting moose calf surveys and installing and monitoring trail cameras, and who shared their knowledge and observations of moose that informed all parts of this study.

I am forever grateful to Jeremi Skelton and Ducks Unlimited Canada for hiring me as a summer student for my first biology field job in 2007. This role allowed me to gain experience in the field of biology and helped solidify my passion for the interface of wildlife, habitat, and agriculture. Thank you to my former colleagues at Golder Associates Ltd. for your understanding and patience during my absence to continue my education.

Finally, I thank all my friends and family, specifically Marcia Brown, Dawson, Gavin and Maxum Carruthers, Riley Ewen, and Lacey, Camryn and Eden Rust, for their patience, care, and encouragement that supported me through my education.

Dedication

This thesis is lovingly dedicated to my nieces:

Camryn and Eden Rust

I hope you always enjoy the outdoors and learning about nature.

Table of Contents

List of Tables

List of Figures

Abbreviations

AAFC	Agriculture and Agri-Food Canada
AIC	Akaike's Information Criterion
BP	Years before the present
CI	Confidence interval
E	Easting
GIS	Geographic information system
GPS	Global positioning system
kg	Kilogram
km	Kilometre
LRS	Lifetime reproductive success
m	Metre
MCP	Minimum convex polygon
MMU	Moose Management Unit
MVC	Moose-vehicle collision
N	Northing
NAD83	North American Datum of 1983
NDVI	Normalized Difference Vegetation Index
PPR	Prairie Pothole Region
RSF	Resource selection function
SCIC	Saskatchewan Crop Insurance Corporation
SD	Standard deviation
SGI	Saskatchewan Government Insurance
SK	Saskatchewan
SR	Selection ratio
SWF	Saskatchewan Wildlife Federation
U.S.	United States
UTM	Universal Transverse Mercator
VHF	Very high frequency
VIT	Vaginal implant transmitter
WMZ	Wildlife Management Zone

Chapter 1: General Introduction

1.1. Thesis Structure

This document was prepared in the format of a manuscript-style thesis. The first chapter presents a general introduction to the theme of my research and the second chapter provides a critical review of the relevant literature. The manuscript chapter, Chapters 3, has been developed as an independent scholarly manuscript written in preparation for publication in a peer-reviewed journal. My final chapter (Chapter 4) summarizes and integrates the key results of my research and provides recommendations for applying these findings to manage this relatively new moose population. These conservation and management recommendations are intended for government agencies and other stakeholders.

1.2. Background and Introduction

1.2.1. Habitat Alteration and Species Response

Anthropogenic-caused habitat loss and fragmentation are widespread throughout North America and have been identified as one of the primary drivers of declines and extinctions in mammal populations (Kosydar et al. 2014). Habitat loss and degradation are also considered the greatest threat to biodiversity (Ehrlich 1988, Wilson 1992). Currently, species extinction rates are 100 to 1000 times greater than pre-human levels (Pimm et al. 1995). In the United States, agricultural practices including crop production and livestock grazing are the most widespread types of habitat alteration and negatively impact 38% of endangered species (Wilcove et al. 1998). The modification of the landscape for agriculture and other purposes leaves remnant patches of isolated native vegetation (Saunders et al. 1991). Transformation of the prairie landscape in North America has resulted in a complex agro-ecosystem of wetlands, patches of forest, grassland areas used for hay production or livestock grazing, and extensive monocultures of single species crops such as corn, canola, wheat, barley, oats, and pulse crops (Samson and Knopf 1994, Acton et al. 1998, Ramankutty and Foley 1999, Hammermeister et al. 2001, Asner et al. 2004, Samson et al. 2004, Agriculture and Agri-Food Canada [AAFC] 2014a, AAFC 2014b). Importantly, while some wildlife species have been negatively impacted by agriculture, other species have adapted and thrived over the last century in this unique ecosystem, such as the white-tailed deer (*Odocoileus virginianus*) (Halls et al. 1984, McCabe and McCabe 1984,

Alverson et al. 1988, Conover 1997, Porter and Underwood 1999, Desmarais et al. 2000, Côté et al. 2004, Dawe 2011). Much more recently, over the last several decades, moose (*Alces alces*) have adapted to the agricultural landscape (Laforge et al. 2016), perhaps because moose are more flexible in terms of diet and habitat requirements than previously thought (Peek 2007).

1.2.2. Resource Selection

Resource selection is perhaps best described as the use of a resource, either a habitat type or a food item, relative to its availability (Johnson 1980). Habitat and resource selection research previously focused on the current selection of resources and how to manage habitats; however, recent work in this area focuses on predicting habitat quality and the future success of a species (Fortin et al. 2008). Selection can be positive or negative, positive referring to a component being used more than its availability (i.e., selected for), and negative selection meaning using a component less than its availability (i.e., selected against). However, to improve clarity, I will use the term *selection* in reference to moose using a resource disproportionately greater than its availability, and the term *avoidance* to indicate the opposite. A resource selection function (RSF) is a powerful method to quantify animal habitat suitability and use (Manly et al. 2002). RSFs are developed to predict the probability of occurrence of a species based on a set of environmental variables (Boyce 2006). Depending on study design, RSFs can compare the attributes or environmental covariates of used resources with either unused or available resources for each individual animal in a population (Thomas and Taylor 2006).

1.2.3. Moose Ecology and Habitat Selection

Moose are ungulates or hooved animals and are the largest mammalian herbivore of the deer or cervid family (*Cervidae*). Mature adults measure 1.8 to 2.1 metres (m) at the shoulder and weigh up to 500 kilograms (kg) and 710 kg for females and males, respectively (Bubenik 2007). Height and weight vary by moose subspecies. Mammals with life history characteristics such as slower growth rates, maternal care of young, larger mass, larger home ranges, and increased niche specialization have significantly lower abundances in fragmented habitats (Kosydar et al. 2014). Moose possess most of these life history characteristics (Peek 2007). Moose are considered selective generalists and use specific forage or habitat components in higher proportions than they are available, but will occupy a wide variety of habitats (Peek

2007). Species-specific strategies of habitat selection (i.e., specialist or generalist strategies) influence how a species is distributed in space and time, and population dynamics (Brown and Rosenzweig 1986, Fortin et al. 2008).

Habitat selection by moose is influenced by a number of factors including climate, forage, habitat availability, population density, predation, competition, and life-cycle states (Brown and Rozenweig 1986, Montgomery et al. 2013). Moose are most commonly found in areas dominated by forest cover with spruce (*Picea* spp.), fir (*Abies* spp.), and pine (*Pinus* spp.), and where forest vegetation communities have historically evolved with fire (Odum 1983, Telfer 1984). Food and cover limit the geographic distribution of moose to the north (Kelsall and Telfer 1974), while climate is thought to limit their distribution to the south (Renecker and Hudson 1986).

1.2.4. Moose Distribution

Moose have a circumpolar distribution in the northern hemisphere and have been present in the boreal and mixed-wood forests of North America for thousands of years (Peterson 1955, Reeves and McCabe 2007). There are currently four subspecies of moose in North America (Bubenik 2007). Shiras Moose (*Alces alces shirasi*) are found in British Columbia and Alberta in Canada, and in Montana, Idaho, Colorado, and Wyoming in the United States (U.S.). The Northwestern Moose (*Alces alces andersoni*) has the largest range of the four subspecies. This subspecies occurs in Canada in the Yukon, Northwest Territories, Nunavut, British Columbia, Alberta, Saskatchewan, Manitoba and Ontario, and in the U.S. in northern Michigan and Minnesota. The Eastern or Taiga Moose (*Alces alces americana*) occurs in Maine in the U.S. and in Nova Scotia, Quebec, Ontario, and Newfoundland in Canada. Moose were introduced into Newfoundland in 1895 and 1904 and are now well established (Bubenik 2007). The Alaskan/Yukon or Tundra Moose (*Alces alces gigas*) occurs in Alaska, U.S., and in the Yukon Territory and northern British Columbia, Canada. Hybridization is possible between *Alces alces andersoni* and the three other subspecies where their ranges overlap (Bubenik 2007). Moose regularly inhabit the tundra north of the treeline in Alaska and near the Horton River in the Northwest Territories and Nunavut (Kelsall 1972).

Within the last century, the distribution of moose has extended into areas considered previously unoccupied including into Labrador and north of Lake Superior in Canada, and south along the Rocky Mountains in the U.S. (Telfer 1984, Karns 2007). Moose distribution extended into the temperate rainforests of British Columbia, Canada (Darimont et al. 2005), and into northern Utah by the early 1950s (Babcock et al. 1982). In 2000, moose populations occurred in 11 Canadian provinces and territories and in at least 17 states in the U.S., with the North American moose population estimated at 1 million (Timmerman 2003).

Recent anthropogenic-caused global climate change has affected the physical and biological systems on all continents (Rosenzweig et al. 2007). Climate change has caused range contractions and expansions in terrestrial vegetation and wildlife (Warren et al. 2011, Cheaib et al. 2012), including range shifts poleward or into higher elevations (Rosenzweig et al. 2007). Climate change has also contributed to species extinctions and biodiversity loss (Opdam and Wascher 2004, Warren et al. 2011). In Canada, the overall climate has been warming over the last century (Redmond and Abatzoglou 2014). Statistically significant warming trends affecting the Canadian prairies have been evident in winter and to a lesser extent in spring (Isaac and van Wijngaarden 2012). Typically, arid conditions extend into the Canadian Prairies, but in central Canada a large increase in precipitation has been demonstrated by both regional North American satellite data from 1979 to 2011 (Ohring et al. 2014) and climate station data from 1901 to 2009 (Redmond and Abatzoglou 2014).

Moose are intolerant of heat, and temperature has a cumulative influence on survival (Lenarz et al. 2009). Schwab (1985) suggested that moose habitat selection could be explained by climate and moose avoiding heat stress. Moose are very tolerant of cold temperatures, but are easily heat-stressed throughout the year (Renecker and Hudson 1986). Shade is important for thermoregulation (Lenarz et al. 2011), but moose also make frequent use of waterbodies, likely for critical thermoregulation. North American moose select aquatic habitats in the boreal forest (Peek 2007), and this combined shade and access to water in wetlands would provide moose with both optimal forage and thermal shelter. The habitat selection of moose in south-central Saskatchewan suggests that land cover types that provide water and shade in summer, and thermal cover in winter, such as trees and wetlands, are the most important to moose survival on the Canadian prairies (Laforge et al. 2016).

1.2.5. Moose Range Expansion

Over the past 20 years, moose have been documented as making extensive use of farmland areas in Canada (Laforge et al. 2016) and in prairie landscapes in Montana, U.S. (DeCesare et al. 2014). The landscape in North America has been transformed and highly fragmented by agricultural practices such as crop production and seeding of agronomic forage species for hay and livestock production. The selection of wetlands and woody cover provide an explanation for the successful expansion of moose into farmland habitats (Laforge et al. 2016). Moose in the prairie landscape of eastern Montana inhabit wetlands along the Missouri River and other areas supporting willow (*Salix* spp.) communities (DeCesare et al. 2014). Moose distribution in Montana and throughout the Rocky Mountains has increased since the mid-1800s (Karns 2007). Although Montana has agricultural land use, in 2012 less than 20% of Montana was used for crop production and 42% of Montana was used as pasture and rangeland (National Agricultural Statistics Service 2018). Moose occur in northern Minnesota with declining populations (Dybas 2009). Northeastern Minnesota is predominantly forest, while northwestern Minnesota is dominated by sugar beet and wheat crops (Minnesota Department of Agriculture 2019). In Saskatchewan, Laforge et al. (2016) found that moose selected for the small remaining areas of wetlands and woody cover on an agriculturally dominated landscape with 62% cropland and 18% pasture and grassland cover (Laforge et al. 2016). Moose did not exhibit strong selection for any of the crop types typically grown in the study area, such as cereals, oilseeds or pulse crops (Laforge et al. 2016).

The specific factors driving the southward range expansion of moose into farmland are poorly understood. This range expansion is occurring in an area largely devoid of forest cover (AAFC 2014a). A combination of favorable climatic conditions, a lack of large predators, and a decline in the rural human population in Saskatchewan have likely contributed to the range expansion of moose into southern Saskatchewan (Laforge et al. 2016, Laforge et al. 2017). Successful range expansion of mammals has often been associated with higher introduction effort by humans, and the ability for the species to produce large and frequent litters (Capellini et al. 2015). There is no evidence to suggest that the expansion of moose into farmland has been aided by human translocations, nor do moose possess the life history traits of large and frequent litters. Moose will most often produce one or two young per year and the occurrence of triplets is very rare (Franzmann and Schwartz 1985). Geist (1974) describes a hypothesis that explains the

dispersal and range expansion observed in moose based on habitat use. Moose utilize seral plant communities. These communities occur post-disturbance and are unpredictable in temporal and spatial scales, which results in juvenile dispersal. Moose prefer post-disturbance forest habitat, where fire or logging disturbances have created early successional forests that provide abundant forb and woody re-growth (Peek 2007). This habitat association with disturbed and edge habitats likely partially explains why the species has successfully spread into the fragmented agriculture-dominated landscape. However, this hypothesis does not explain the timeline of expansion. Why in the last approximately 20 years has this range expansion occurred, and not over 100 years ago when large carnivores were essentially extirpated from this area and land was first cultivated for agricultural production?

A combination of factors including distinct climatic and vegetation changes, increased precipitation, wetland basins with higher than average spring water levels, rural depopulation of Saskatchewan and a relative lack of large predators likely contribute to the successful expansion of moose in Saskatchewan. Distinct vegetation changes such as increased biomass in the arctic tundra region, Canadian Prairies, and in parts of the U.S. Northern Great Plains have been demonstrated using the satellite-observed Normalized Difference Vegetation Index (NDVI) (Ohring et al. 2014). The NDVI also shows decreased vegetation cover in the boreal forest zone of North America within the last 26–28 years prior to 2014 (Ohring et al. 2014). This decreased vegetation cover has been interpreted as a reduction in forest growth due to the interacting influences of temperature, precipitation, water availability and disturbance by fire, insects, and disease (Goetz et al. 2005, Verbyla 2011). These vegetation changes likely have influenced the expansion of moose southward. Despite the warming climate trend, the trend of increased precipitation in the Canadian Prairies (Ohring et al. 2014, Redmond and Abatzoglou 2014) likely aided moose in adapting to the climate and heat stress that was previously believed to limit their distribution to the south (Renecker and Hudson 1986). In May 2011, 2012, 2013, 2014 and 2015, spring water levels in wetland basins in southern Saskatchewan were 57%, 32%, 39%, 33%, and 24% higher than the long-term average, respectively (U.S. Fish and Wildlife Service 2011, 2012, 2013, 2014, 2015).

Rural human depopulation in Saskatchewan may be aiding moose range expansion. The response of wildlife to rural human depopulation has been studied with carnivore populations (Enserink and Vogel 2006, Navarro and Pereira 2012). Humans are responsible for the majority

of carnivore mortality worldwide. Carnivore mortality decreases with reduced human presence on the landscape (Enserink and Vogel 2006, Committee on the Status of Endangered Wildlife in Canada 2012, Navarro and Pereira 2012, Ohrens et al. 2016). The same principle may apply to large ungulates; however, if populations of large carnivores increase in the depopulated area, the predation risk to large ungulates will likely increase and may even exceed the perceived risk of predation from humans. Large carnivores have not become more abundant as a result of this moose range expansion and therefore, are not considered a regulating factor at this time.

1.2.6. Wildlife Management Implications

Regardless of the drivers facilitating moose range expansion, understanding population dynamics and habitat use patterns are necessary steps in guiding the management of any wildlife species. Government capacity and funding to conduct ungulate population surveys is often limited. Infrequent population surveys can be inaccurate or provide little more than a vague indication of the population size at a specific point in time. It is necessary to understand changes in populations due to dispersal, reproduction, and calf survival to improve our understanding of the demographic rates affecting population trends. Population density and ecology are relatively unknown for the moose population expanding into Saskatchewan farmland, in some cases extending well south of the boreal forest and aspen parkland.

Understanding reproductive measures and habitat selection in this expanding moose population could also provide valuable insights for the management and conservation of moose populations that are in declining in North America. Jurisdictions in North America that are experiencing moose declines include Alaska (Timmerman 2003), Manitoba, Ontario, (Ontario Ministry of Natural Resources and Forestry 2016), Minnesota (Murray et al. 2006, Wildlife Management Institute 2014, Morse 2015, Minnesota Department of Natural Resources 2016), New Hampshire, Montana, Wyoming (Wildlife Management Institute 2014, Morse 2015), and Nova Scotia (Pulsifer and Nette 1995, Parker 2003, Broders et al. 2012), as well as three regions within British Columbia (British Columbia Ministry of Forests - Lands and Natural Resource Operations 2014). In response to these declines some jurisdictions have initiated research projects (British Columbia Ministry of Forests - Lands and Natural Resource Operations 2014, Minnesota Department of Natural Resources 2016). Other jurisdictions have implemented lower

hunting quotas, and in severe cases have closed hunting seasons (Parker 2003, Wildlife Management Institute 2014, Morse 2015).

If moose reproductive success in the agricultural landscape is too high, the population could be managed through hunting (i.e., with more antlerless hunting licenses made available). If reproduction is low or unsuccessful, further research may be required to determine what the limiting factors are and how these can also be managed (e.g., fewer licenses). Moose are high-profile big game animals and are typically managed to have a population surplus to support licensed and subsistence hunting (Parker and Gillingham 2007). However, overabundant moose are often associated with socio-economic challenges. Moose inhabiting areas with high traffic volumes and agricultural activity increases risks of human-moose conflicts, which presents relatively new and unique challenges for wildlife managers in this area. Conflicts include moose-vehicle collisions (MVCs), public safety, and damage to planted trees and shrubs, fences, agricultural crops and harvested grain.

Habitat selection influences the location and number of human-ungulate conflicts including MVCs and crop damage (Andreassen et al. 2005, Sorensen et al. 2015). Habitat selection influences ungulate road crossing locations and associated ungulate-vehicle collisions (Andreassen et al. 2005, Hurley et al. 2007, Becker et al. 2011). Moose-vehicle collisions pose a human and wildlife safety issue throughout much of Canada. Joyce and Mahoney (2001) reported that 5,422 MVCs occurred between 1988 and 1994 in Newfoundland. On major highways in British Columbia, 6,512 MVCs were reported from 1988 to 2007, with annual MVCs ranging from 152 to 516 (Sielecki 2007).

In the agricultural region of Saskatchewan, MVCs have increased with the southward range expansion of moose. In November 2012, the Saskatchewan Government Insurance (SGI) agency began collecting information about collisions, including which species of wildlife was involved. Therefore, long-term trends on species-specific wildlife collisions are unknown.

It is well-established that overabundant moose populations damage natural and commercial regenerating forests (Ball and Dahlgren 2002, Bergqvist et al. 2003, Wallgren et al. 2013). However, agricultural crop damage is a relatively new human-moose conflict (Laforge et al. 2017). In the past, crop damage has been primarily associated with other ungulates such as white-tailed deer, mule deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*; Irby et al. 1996, Fagerstone and Clay 1997, Brook 2009, Sorensen et al. 2015). In Saskatchewan from 2000 to

2012, 19,069 confirmed crop damage claims were paid to farmers for damage caused by white-tailed deer, mule deer and elk (Sorensen et al. 2015). From 1993-2012, 819 confirmed moose crop damage claims were recorded in Alberta, Saskatchewan, and Manitoba with canola, oats and wheat being 36%, 17%, and 13% of the crops damaged, respectively (Laforge et al. 2017).

Understanding the home range size and habitat selection of parturient and post-parturient female moose with young will provide a missing link for the management of this newly-established population. This research may show the importance of wetlands and isolated trees and shrubs associated with riparian areas, inactive farmyards, and shelterbelt tree rows to reproductive female moose in a landscape dominated by cropland. If so, conservation and land management practices and policies will need to be revisited, as these small areas of important habitat surrounded by cropland may be of higher conservation value than originally thought. These areas may then become a conservation priority for governments and conservation groups. Alternatively, these areas could be viewed as attractants for moose that increase the risk of human-moose conflicts, such as MVCs and crop damage. It may then be desirable to strategically remove some of these areas of habitat to reduce such risk. Areas of habitat could be established elsewhere to reduce risk while maintaining suitable moose habitat in lower-risk areas. The analysis of habitat selection for this expanding moose population will be valuable in guiding habitat conservation practices and moose management. Ultimately, such practices and management will depend on society's desire for this moose population to persist.

1.3. Thesis Objectives

The objectives of my thesis were to (1) determine reproductive measures, such as pregnancy and twinning rates, of adult female moose in a population that has recently expanded into farmland areas of Saskatchewan, (2) identify the general calving period of this moose population and estimate specific parturition sites of individual moose, (3) quantify the strength of selection for specific habitat types by female moose for use as parturition sites, (4) estimate home range size for post-parturient female moose with young, (5) characterize resource selection by adult female moose during the first 20 days post-parturition when calves are most vulnerable.

1.4. Hypothesis

I hypothesize that adult female moose will primarily select for high quality hiding cover during parturition. I hypothesize that post-parturient female moose with young calves will select both hiding cover and high quality foraging habitats. I hypothesize that habitat use by parturient and post-parturient adult female moose will be influenced by availability of wetlands with tree and shrub cover and by distance from roads. I predict that female moose will select wetlands and their associated riparian areas, as well as trees and shrubs not associated with wetlands. I hypothesize that native grassland and pasture and hay land (i.e., forages) will also be important to female moose with neonates due to the lower amount of human disturbance compared to annual cropland. Additionally, the early availability of nutritious forage on native grassland and in pasture and hay land, as compared to cropland, might also act as an attractant for female moose with young. In Chapter 3, I expand on these hypotheses by developing and evaluating selection ratios and multiple competing hypotheses to predict the probability of resource use by parturient and post-parturient female moose in an agriculture-dominated landscape. Based on the relative lack of traditional forest and wetland habitat, I hypothesize that reproductive measures of female moose will indicate that the majority of habitat is of low quality.

Chapter 2: Review of Moose Ecology and the Origins of Farmland Moose

2.1. Moose in Saskatchewan: Historical to Current Distribution

Historically, moose in Saskatchewan (SK), Canada, were broadly distributed across the boreal forest, Aspen Parkland (Berg and Phillips 1974, Reeves and McCabe 2007), and Cypress Upland Ecoregion (Acton et al. 1998). Moose are found north of the Boreal Shield and Boreal Plain Ecozones, in the Taiga Shield Ecozone at average densities of one moose per 25 km^2 (Acton et al. 1998; Figure 2.1). Historically, the Cypress Upland Ecoregion acted as an 'island' of forested habitat suitable for moose surrounded by Mixed Grassland (Acton et al. 1998). Moose were introduced to the Alberta side of Cypress Hills Provincial Park in 1956 (Barrett 1972). Moose have long been established within forested 'islands' of habitat throughout the Canadian prairie provinces of Alberta, Saskatchewan, Manitoba, and in North Dakota and Minnesota (Karns 2007). Moose Mountain Provincial Park in southeastern Saskatchewan is one of these 'islands' of forest habitat that supports resident moose (Karns 2007).

Recently, moose have expanded their range southward to encompass their pre-European range, which coincides with the Aspen Parkland Ecoregion (Berg and Phillips 1974, Reeves and McCabe 2007). In Saskatchewan, moose have expanded even further south into agriculture-dominated landscapes (i.e., farmland) within the Moist Mixed Grassland and Mixed Grassland Ecoregions (Laforge et al. 2016). It is widely accepted that, historically, frequent transient or resident moose did not inhabit throughout the Moist Mixed Grassland and Mixed Grassland Ecoregions of Saskatchewan (Reeves and McCabe 2007).

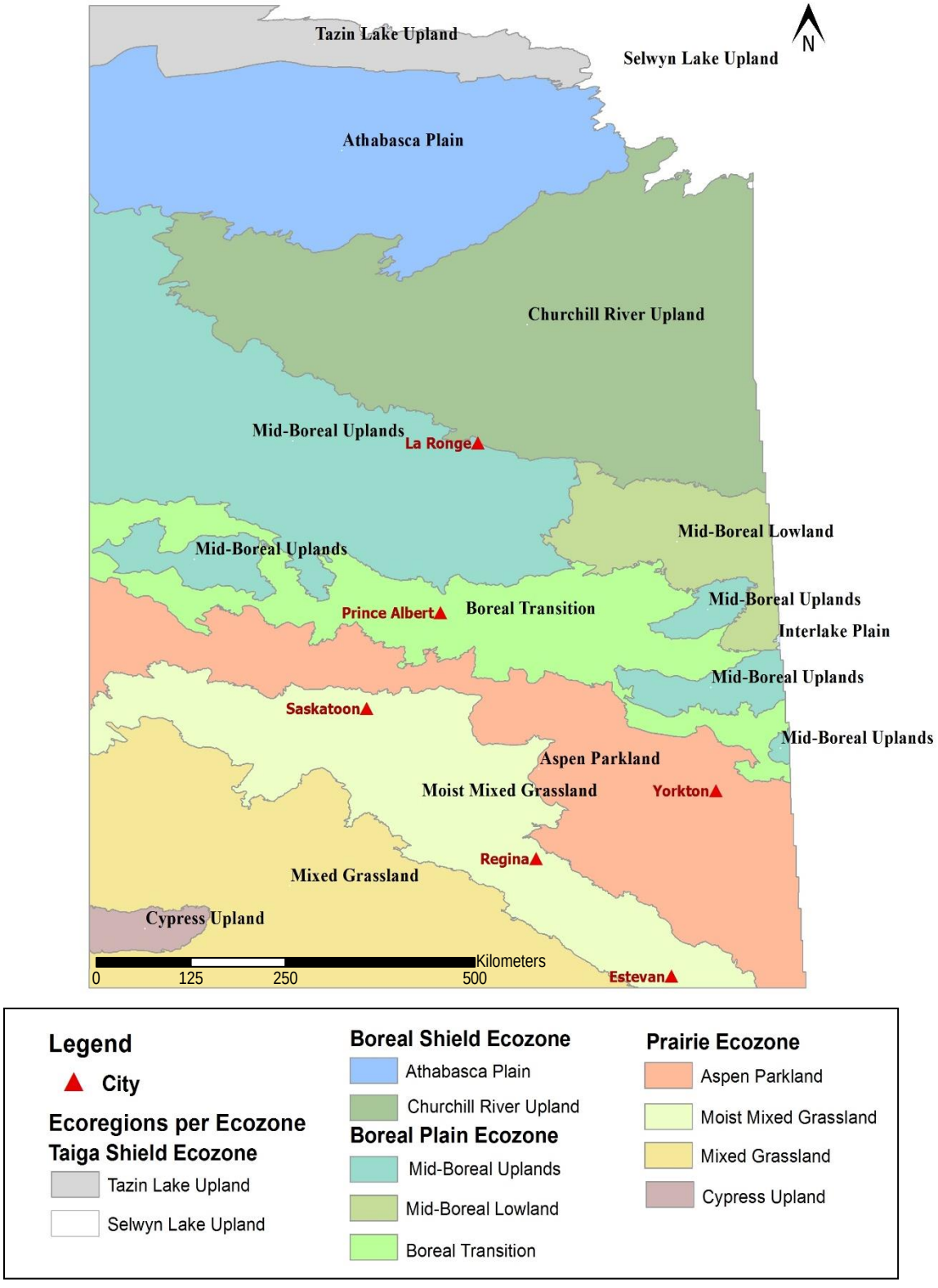

Figure 2.1 Ecozones and Ecoregions of Saskatchewan (after Acton et al. 1998). Resident moose were not frequent in the Moist Mixed and Mixed Grassland Ecoregions at the time of European contact (Reeves and McCabe 2007).

Faunal assemblages from studied archaeology sites is an additional line of evidence to determine the former range of moose in Saskatchewan. However, faunal materials are often only collected if they exhibited evidence of human modification (Novecosky 2003), leaving many mammalian bone fragments unidentified. Nonetheless, in the Moist Mixed Grassland Ecoregion, moose bones were identified at the Harder Archaeological Site approximately 25 km west of Saskatoon, Saskatchewan in the NE 27 and NW 26-37-08 W3M (Dyck 1970). Of the 102 bones collected from the site, 9 were identified as moose, while the majority (89 of 102) was from bison (*Bison* spp.; Dyck 1970). The Harder site was radiocarbon-dated to 3,410 BP ± 120 and represented a long-term summer occupation of the Oxbow people (Dyck 1970). Moose were not identified in the faunal assemblages at the Cactus Flower site in southeastern Alberta, or the Redtail and Thundercloud sites in Wanuskewin Heritage Park near Saskatoon (Webster 1999). Moose bone was observed in the faunal assemblage at the Crown site located at Nipawin, SK, northeast of Saskatoon in the Boreal Transition Ecozone (Webster 1999). The cultural occupations of the Crown site date back to approximately 4,330 BP (Webster 1999).

Further south at the Sjovold site, located near the South Saskatchewan River in the Moist Mixed Grassland Ecoregion, approximately 5 km south of Outlook, SK, archaeologists discovered four moose bone fragments that were dated from a human occupation in the range of 770 to 1170 BP (Dyck and Morlan 1995). However, excavations at this site suggest that bison (*Bison bison*) and other mammals were more plentiful than moose (Dyck and Morlan 1995). Either moose were not as common in the area or the people occupying the site did not rely on moose for subsistence as much as they did on other mammals such as bison. Approximately 10 km south of Estevan, SK in the Aspen Parkland Ecoregion of southeastern Saskatchewan at the Long Creek site, evidence of moose was not found among the faunal assemblage discovered during the 1957 excavation (Bryant 2002). Over several cultural occupations, bison and medium-sized canids were the most abundant faunal materials. Only one deer (*Odocoileus sp*.) bone fragment was discovered, representing the only large game species other than bison (Bryant 2002). At the Antelope Creek and Miry Creek sites in the Mixed Grassland Ecoregion of southwestern Saskatchewan, moose bones were not identified (Novecosky 2003).

The journal observations of explorers, prior to widespread European expansion in North America, are an additional line of evidence to determine the former range of moose in Saskatchewan. In 1754–1755, Anthony Henday spent a year with a group of Indigenous people along the North Saskatchewan River. Although his specific travel route is not entirely clear, he did observe moose, elk, and bison. During this time, Henday travelled as far southwest as Olds, AB and as far east as the Eagle Hills, approximately 14 km southwest of North Battleford, SK (Belyea 2000). The journal observations of Henday describe on most days that the Indigenous hunters killed one to three moose, and occasionally up to eight (Belyea 2000). These journal observations suggest that moose were plentiful along the North Saskatchewan River in the Aspen Parkland and Boreal Transition Ecoregions of Saskatchewan in the mid-18th century prior to widespread European expansion and the conversion of natural ecosystems to farmland.

Historical moose hunting quotas in Saskatchewan is an additional line of evidence demonstrating the expansion of moose. Saskatchewan's 83 Wildlife Management Zones (WMZs) are categorized as the following: boreal forest (WMZ 56–73), forest fringe (WMZ 48–55), parkland (WMZ 31–47), farmland (WMZ 15–30), and grassland (WMZ 1–14) zones (Government of Saskatchewan 2018a). Several of these zones are further split into east and west sections (e.g., 14E and 14W). Prior to 2000, the Saskatchewan Ministry of Environment developed Moose Management Units (MMUs) that overlapped the boreal forest, forest fringe, some parkland WMZs, and the islands of moose habitat in the Moose Mountain and Cypress Hills areas (Arsenault 2000). The MMUs were not developed throughout Saskatchewan and did not overlap the majority of farmland or grassland WMZs. In 2000, moose hunting licenses were available in only one of the thirty farmland and grassland WMZs in Saskatchewan (WMZ 6; Government of Saskatchewan 2014, unpublished data). For the first time in 2009, hunting licenses for moose were available in the farmland WMZs 22 to 24 and 26 to 29. These licenses were available through the Saskatchewan Big Game Draw in an effort to manage the expanding moose population (Saskatchewan Ministry of Environment 2014, unpublished data). As of 2019, moose are hunted in all Saskatchewan WMZs, with the exception of two zones, one in southwest Saskatchewan (WMZ 3), and another in southeast Saskatchewan (WMZ 15; Government of Saskatchewan 2018a, 2018b, 2019a, 2019b).

Moose inhabiting the agriculture-dominated areas of Saskatchewan represent an expanding population, which prior to this research, has been largely unstudied with few exceptions (see

Laforge et al. 2016, 2017). It is likely that the southward range expansion of moose in Saskatchewan began between 1999 and 2006, approximately 14 to 21 years ago, based on Saskatchewan moose range maps (Arsenault 2000, 2009). Although no current estimates are available, in 1999, it was estimated that 2% of the province's approximately 45,516 moose were in the farmland and grassland WMZs (Arsenault 2000).

In 2011, the Saskatchewan Ministry of Environment (2013) estimated that the Saskatchewan winter moose population was approximately 57,000 animals with numbers in the parkland and farmland wildlife management zones increasing. In 2011, moose populations in the forest fringe were considered at or slightly above the long-term winter average (Saskatchewan Ministry of Environment 2013). The population in the boreal forest was considered stable, but slightly below the long-term winter average (Saskatchewan Ministry of Environment 2013). In 2016, the boreal forest moose population was in decline with a population below the long-term winter average (Saskatchewan Ministry of Environment 2017). Currently, the boreal forest moose population continues to decline with population estimates 30 to 50% below the long-term winter average (Government of Saskatchewan 2018a, 2018b). This population decline is occurring while previously increasing moose numbers in parkland and farmland WMZs have stabilized or even declined due to liberal license quotas in the past few years (Government of Saskatchewan 2018a). Despite a warming climate in North America (Redmond and Abatzoglou 2014) and severe habitat fragmentation of the Prairie Pothole Region (Acton et al. 1998), moose have expanded their range southward in Saskatchewan during the past 20 years.

2.2. Resource Selection

A resource is defined as a biotic or abiotic factor that influences an organism's ability to survive and reproduce (Thomas and Taylor 2006). Therefore, a resource is anything that influences the ecology of an organism, including food items and land cover (Johnson 1980). Resource selection is the process in which organisms choose habitats, food items, or other resources that maximize their fitness (Brown and Rosenzweig 1986). Resource selection is specific to a species, population or individual (Dettki et al. 2003), varies across spatial and temporal scales (Laforge et al. 2015, 2016) and is density-dependent within and between species (Fretwell and Lucas 1969, van Beest et al. 2014). Selection can be positive or negative, positive referring to a component being used more than its availability (i.e., selected for), and negative

selection meaning using a component less than its availability (i.e., selected against). Note that selection is not the same as preference, and I do not use the latter term. The term preference refers to what an animal would choose if offered all food items on an equal basis independent of availability (Pirnie 1935, Ellis et al. 1976). In such a scenario, food items could then be ranked from most to least preferred (Johnson 1980). However, these scenarios are difficult, if not impossible, to produce and control in the wild.

There are many reasons why studying and understanding resource selection of a species is important to conservation and management. The primary reason for this type of research is often to infer habitat quality and trends to facilitate species management. Peek (1974) argued that having knowledge of forage preferences is a prerequisite to evaluating habitat conditions and trends. Knowledge gained from habitat and resource selection studies is used to manage the species or the habitat the species uses.

In boreal ecosystems in North America and Scandinavia, research has been often targeted to better understand how forest management practices (e.g., forest harvesting, clear-cutting) interact with moose habitat and forage selection (Peek et al. 1976, Hamilton et al. 1980, Thompson and Vukelich 1981, Schwab 1985, Bergström and Danell 1987, Danell et al. 1991a, Danell et al. 1991b, Edenius et al. 1993, Heikkilä and Härkönen 1996, Rempel et al. 1997, Courtois et al. 2002, Ball and Dahlgren 2002, Bergqvist et al. 2003, Potvin and Bertrand 2004, Månsson et al. 2009, van Beest et al. 2010, Speed et al. 2013, Wallgren et al. 2013).

Other valuable research objectives of resource selection analysis are to understand and manage or reduce human-wildlife conflicts including forest and agricultural crop damage or wildlife-vehicle collisions (Ball and Dahlgren 2002, Andreassen et al. 2005, Hurley et al. 2007, Becker et al. 2011, Laforge et al. 2017). Resource selection research can focus solely on current resource use and how to manage or manipulate habitats, or be expanded to predict habitat quality and the future success of a population or species (Fortin et al. 2008).

2.2.1. Habitat Selection

Habitat is any portion of the surface of the earth where a species is able to colonize and live (Fretwell and Lucas 1969). Habitat is comprised of the resources and conditions present in the area an organism occupies (Hall et al. 1997). The total area available to a species can be divided into different habitats based on land cover or other environmental conditions.

Species-specific strategies of habitat selection (i.e., specialist or generalist strategies) influence how organisms are distributed in space and time (Fortin et al. 2008, Brown and Rosenzweig 1986). A species that is highly specialized in terms of resource use has developed a specialist strategy (i.e., a specialist), while a species that can use a wide range of resources uses a generalist strategy (i.e., a generalist). Specialist individuals have the highest fitness at low population densities, while generalists have higher fitness in dense populations (Fortin et al. 2008). Moose have been described as selective generalists, in that they select for specific forage or habitat components in higher proportions than they are available, but will make use of a wide variety of more marginal habitats when necessary (Peek 2007).

The heterogeneity of landscapes is known to influence many ecological processes (Hobbs 2003). Ecological processes, including habitat selection occur on different spatial and temporal scales and are therefore influenced by space and time (Boyce 2006). Animal distribution and forage selection can be scale-dependent with different movement patterns and use of forage among seasons (Månsson et al. 2007, van Beest et al. 2010). Moose habitat selection is influenced by the interspersion of foraging opportunities and cover to reduce predation risk in mixed forests (Dussault et al. 2005a). A number of factors influence moose habitat selection including climate, forage, habitat availability, population density, predation, competition, and life-history states (Brown and Rozenweig 1986, Montgomery et al. 2013). Moose habitat selection varies across spatial and temporal scales (Laforge et al. 2016). Temporal and spatial variation in habitat selection is related to several interconnected factors including the availability, seasonality, and nutritional quality of forage resources, thermal cover, and snow conditions (Telfer 1970, Thompson and Vukelich 1981).

Geist (1971) described moose habitats as being of two types, stable and transitory. Stable habitats include shrub communities in forested areas that were predictable and relatively stable in terms of succession, such as riparian areas along watercourses. Transitory habitats are those that follow major disturbances, such as fire, and are less predictable in space and time (Geist 1971). Although stable habitats are necessary for supporting moose populations between transient habitats, large increases in population generally occur when transitory habitats increase (Peek 1974). The willow (*Salix* spp.) and aspen (*Populus* spp.) communities around wetlands and riparian areas in the Aspen Parkland Ecoregion represent stable habitats that will not transition to

new vegetation or forest communities. These areas are often characterized by abundant woody biomass that is relatively permanent (Berg and Phillips 1974).

Peterson (1955) described preferred moose habitat as forest in continual succession or regeneration. Moose populations increase the most in response to early stages of succession in the boreal forest and decrease as the forest reaches maturity stages (Kelsall et al. 1977, Schwartz and Franzmann 1989). The optimal successional stages of a forest for moose productivity occur between 11 and 30-years post-fire (Kelsall et al. 1977, Schwartz and Franzmann 1989). This typically represents the timeframe when regenerating forests have the highest abundance of browse after being disturbed by fire, wind, disease, or timber harvesting (Parker 2003). The yield of deciduous woody browse was modelled for fire cycles of 38, 50, 75, and 100 years in the boreal forest of Alberta, Saskatchewan, and Manitoba to determine the effects of forest management including intensive timber harvest (Telfer 1995). Total browse production decreased as the length of fire cycles increased. Effective fire suppression during the past 40 to 50 years, at that time, contributed to the low proportion of habitat in the 0 to 20-year forest regeneration class, and low carrying capacity of moose in Alberta's boreal forest (Telfer 1995).

Moose have recently reoccupied a portion of their range within temperate deciduous forest in central and western Massachusetts, USA after a >200-year absence (Wattles and DeStefano 2013). In central Massachusetts, regenerating forests, after timber harvest operations, were the most heavily used of habitat cover types in all seasons (Wattles and DeStefano 2013). In the western portion of the State, regenerating forests were heavily used in summer and fall, conifer and mixed forests in winter, and deciduous forests in spring (Wattles and DeStefano 2013).

Male and female moose select for different habitats (Van Dyke et al. 1995, Leptich and Gilbert 1989). In Maine, females selected for coniferous forest, and cut-over cover types, while males selected for deciduous, mixed, and aspen cover types. Both sexes used bog and water cover types similarly (Leptich and Gilbert 1989). Female and male moose in south-central Montana selected for aspen in spring and summer, shrub-dominated wetlands in spring, and selected against lodgepole pine cover in both spring and summer (Van Dyke et al. 1995). Habitat and elevational use differed seasonally in both males and females, with females inhabiting higher elevations than males (Van Dyke et al. 1995).

Moose select a mosaic of early successional and mature coniferous and deciduous forest (Nikula et al. 2004, Peek 2007), which supplies an adequate amount of both preferred forage and thermal cover. Habitats utilized by moose were categorized by Telfer (1984) as boreal forest, mixed forest, large delta floodplains, tundra, subalpine shrub, and stream valleys. Habitat use on the prairie and agriculture-dominated landscape adds other habitat types, such as cropland, forage crops, and native grassland to the list of potential moose habitats (Laforge et al. 2016). Moose habitat and diet selection have been extensively researched in forest ecosystems in both North American (Thompson and Vukelich 1981, Telfer 1984, Dussault et al. 2005b, Dussault et al. 2006, Montgomery et al. 2013) and Scandinavia (Ball and Dahlgren 2002, Nikula et al. 2004, Månsson et al. 2007, van Beest et al. 2010).

Moose use most of the available boreal forest habitat types in early winter, without any strong selection, including open areas and deciduous forests; however, in late winter moose strongly select for dense coniferous forests (Telfer 1970, Peek et al. 1976). Many studies have specifically focused on habitat selection of moose during the winter or non-growing season (Stevens 1970, Telfer 1970, Hamilton at al. 1980, Proulx 1982, Risenhoover 1986, Danell et al. 1991a, Danell et al. 1991b, Shipley et al. 1998, Jung et al. 2009). Winter is one of the most challenging survival periods for moose during their annual cycles and is likely a population limiting period.

In northern Alberta, Schneider and Wasel (2000) found that moose population density was positively associated with human settlement and suggested that edge effects were important for moose. This positive association with edge and more fragmented heterogenous habitats emphasizes the importance of examining quadratic or nonlinear terms when modelling moose habitat selection. The strong positive association between human settlement and moose density occurred despite the area receiving high hunting pressure, and habitat losses due to road construction, agriculture activities (37% of the land base), and oil and gas development (Schneider and Wasel 2000). In central Norway, in an area of forest and cultivated land, moose selection of cultivated land was highest at night and when crop biomass was high (Bjørneraas et al. 2011). These studies by Schneider and Wasel (2000) and Bjørneraas et al. (2011) represent two of the few existing in which farmland has been considered a habitat type for moose.

Agricultural crop production may be a factor influencing the southward range expansion of moose as annual and perennial crops can provide abundant and easily accessible energy, protein, and other nutrients for cervids. Crops have been shown to provide adequate nutrition to other cervids, including white-tailed deer (Nixon et al. 1991) and elk (Burcham et al. 1999). Commonly seeded annual crop types in Saskatchewan include cereals, oilseeds and pulses (Agriculture and Agri-Food Canada [AAFC] 2014a, 2014b). Laforge et al. (2016) found that female moose in south-central Saskatchewan strongly selected for wetland and forest land cover types with an intermediate percentage of cereal crops. The land cover in this study area was approximately 62% cropland. Developed areas and pulse crops were avoided during both summer and winter seasons (Laforge et al. 2016).

Moose behavioural responses during high ambient temperatures include reduced movement rates (Broders et al. 2012) or temporary reductions in home ranges (van Beest et al. 2011), and the selection of thermal cover (Dussault et al. 2004, Broders et al. 2012, van Beest and Milner 2013, Melin et al. 2014). Schwab (1985) suggests that moose habitat selection could be explained by climate and moose avoiding heat stress. Moose are very tolerant of cold temperatures but can become easily heat-stressed throughout the year (Renecker and Hudson 1986). Increased metabolism, heart and respiration rates, and reduced feed intake were observed during temperatures above -5˚C in winter and above 14˚C in summer (Renecker and Hudson 1986). Shade is important for the thermoregulation of moose (Lenarz et al. 2011), but moose also make frequent use of water and wetlands, likely for critical thermoregulation (Peek 2007). Melin et al. (2014) found that at a daytime temperature threshold of 20°C, moose selected for areas with higher and denser canopy cover. The combined shade and access to water in wetlands provides moose with both optimal forage and thermal shelter.

The network of roads and highways in Saskatchewan fragments wildlife habitat. Paved roads with high levels of traffic can act as physical barriers resulting in genetic differences between ungulate populations on either side (Holderegger and Di Giulio 2010, Corlatti et al. 2009; Epps et al. 2005). Animal crossings can result in vehicle-wildlife collisions with property damage, and animal and human mortality. Road development and subsequent management changes habitat and can make these areas more attractive to wildlife (Beyer et al. 2013). This is particularly true for moose, as transportation corridors create edge habitat and openings in the boreal forest which moose are attracted to (Child 2007). In Ontario and other forested areas,

roads are associated with the conversion of conifer forest to early successional deciduous-conifer mixed forests that provide higher quality foraging habitat for moose (Beyer et al. 2013). At fine scales, moose avoid roads in Ontario, but at the landscape scale they select for areas with moderate road density. In south-central Saskatchewan, where the landscape is agriculture-dominated and large forests are relatively non-existent, transportation corridors do not change the succession or species composition of forests, and therefore moose attraction to roads may not be for the same reasons as in forested landscapes. The draining of wetlands in cropland is becoming a more common practice as technology increases feasibility (Fraser and Fleming 2001, Broughton and Jutras 2013). Cropland drainage can result in drained water congregating near roads. This is particularly true if culverts in roads are too small for adequate water flow, placed higher than the lowest point in the road ditch, or non-existent. This congregation of water supports the development of wetlands, which can moose to these areas in proximity to roads.

Becker et al. (2011) found that 81% of 201 moose highway crossings could be predicted by winter habitat selection. In their study, preferred crossing habitat was relatively flat, low elevation habitat with deciduous shrubs and trees (Becker et al. 2011). The practice of applying de-icing salt to highway surfaces in winter can create artificial sodium licks that attract moose to road corridors (Child 2007). Ungulate avoidance of roads is caused by human disturbances including driving, walking and hunting (Neumann et al. 2011). Hurley et al. (2007) concluded that moose habitat such as wetlands, flat slopes and coniferous forest adjacent to the highway was predictive of increased MVC risk. Based on the existing literature, habitat with its associated forage and cover, is a main predictor of moose occupying areas in proximity to transportation corridors.

2.2.2. Diet Selection

Although highly interrelated to resource and habitat selection, diet selection focuses specifically on what an organism chooses to consume. It has been widely accepted that moose are primarily a browsing species, especially during the winter season, and that grasses and grass-like plants are typically not important in moose diets (Peek 1974). Moose select for the most nutritious and digestible plant parts available, such as leaves, buds, and new growth of woody vegetation, which vary seasonally and with plant species (Belovsky 1978, Renecker and Schwartz 1998). Throughout much of the species range, moose have two main foraging

strategies depending on season. During the growing season, moose are proficient at selecting the most nutrition plant parts, such as select twigs, stems and foliage of young deciduous trees and shrubs. In winter, moose select leaders or twigs of the previous year's growth (Renecker and Schwartz 1998, Parker 2003). However, winter consumption of plant growth up to 7 years old in highly palatable willow species has been observed (Dorn 1970).

Depending on the North American range and availability of these deciduous woody species, poplar (*Populus spp.*), willow, birch (*Betula spp.*), pin cherry (*Prunus pensylvanica*), maple (*Acer spp*.), alder (*Alnus spp*.), hazelnut (*Corylus spp*.) and red-osier dogwood (*Cornus sericea*) are the preferred browse of moose (Pimlott 1953, Dodds 1955, Geist 1963, Prescott 1968, see references in Peek 1974). In northeastern Alberta, Saskatoon (*Amelanchier alnifolia*) was the most commonly used browse species (Nowlin 1978). Broadleaf or forb species are important in spring, summer, and fall diets (LeResche and Davis 1973, and references therein). In Alaska, forbs accounted for 25% of the summer diet of moose, while grasses, sedges and aquatic plants accounted for only 10% (LeResche and Davis 1973). Fireweed (*Chamerion angustifolium*) and Nootka lupine (*Lupinus nootkatensis*) are favored forb species during summer (LeResche and Davis 1973). These favored forb and shrub species are abundant in regenerating or recently disturbed forests where the tree canopy has been partially or completely removed. The increased sunlight and moisture support dense growth of competing tree seedlings, and shrub and forb layers below the browse line of moose.

In the eastern range of moose in North America and in British Columbia, aquatic and semi-aquatic plants make up a large percentage of the summer diet of moose (Ritcey and Verbeek 1969, Parker 2003). Summer diets of moose are typically 1.5 to 3 times more nutritious than winter diets (Schwartz 1992a). Summer is a critical time to maximize energy intake and create fat reserves that support the individual, and developing fetuses in females, through the negative energy balance experienced during winter (Schwartz 1992a). Negative energy balances in winter occur due to the generally poor quality and quantity of forage and high energy expenditure associated with cold temperatures and travel in snow.

Moose rumen contents collected in late winter in the Cypress Hills Provincial Park of southeastern Alberta contained 56% Saskatoon (*Amelanchier alnifolia*), 21% trembling aspen (*Populus tremuloides*), and 12% chokecherry (*Prunus*) species (Barrett 1972). In winter or during other times when preferred deciduous browse is limited or resources have been exhausted,

coniferous trees such as pine (*Pinus* spp.) and fir species (*Abies* spp.) are considered more important as forage in some areas of Scandinavia (Danell et al. 1991a, Danell et al. 1991b, Shipley et al. 1998, Wam and Hjeljord 2010) and North America (Stevens 1970, Bryant and Kuropat 1980, Albright and Keith 1987). Conifers were not found to be important in the diets on Alaskan moose (Peek 1974) and although commonly available, conifers are considered part of a starvation diet in southwestern Nova Scotia, Canada (Parker 2003). During the winter, moose in mainland Nova Scotia prefer a mosaic of regenerating mixed forest for food and mature conifer cover for escape and thermal cover (Parker 2003).

2.2.3. Resource Selection Functions

Resource selection studies assume that animals select habitats and food to improve reproduction and survival (Manly et al. 2002, Thomas and Taylor 2006). The resource selection function (RSF) is a powerful analytical method to quantify and predict habitat suitability and use (Manly et al. 2002). The RSF is a function proportional to the probability of resource unit or area use by an animal (Manly et al. 2002). RSF analyses have been used in wildlife research studies that focus on a variety of species, including moose (van Beest et al. 2010a, Laforge et al. 2016). A resource is defined as a specific point or area representing a location on the landscape. The attributes of the resource can then be described and measured, in terms of independent covariates such as habitat or land cover, distance to a feature of interest (i.e., road, town, river, etc.), or the proportion of habitat types in the immediate or surrounding areas. These covariates can be categorical (e.g., land cover type), continuous (e.g., distance to a feature), binary (i.e., in a provincial park: yes or no), or proportional (e.g., percentage of a habitat type) (Boyce and McDonald 1999). The proportion of habitat types within a buffered location point describes important habitat trade-offs, interactions, and edge effects (McLoughlin et al. 2006, Hebblewhite and Merrill 2008, Chetkiewicz and Boyce 2009).

Depending on study design, RSFs compare the attributes (i.e., environmental covariates) of used resources with either unused or available resources for a population or individual animal (Thomas and Taylor 2006). Used resources are identified by confirmed animal locations, relocations of an individual animal, or animal sign, such as pellets or tracks (Manly et al. 2002). Available resources are locations that are physically available to the animal (i.e., within a population's range or individual animal's home range; Manley et al. 2002). Available resources

are those where use has not been observed. However, these available resources could have been used and therefore can not be defined as unused resources. Unused resources are locations that are available, but with the confirmation that the population or individual has not used the resource (Manley et al. 2002).

RSFs are typically fitted using a generalized linear regression model (Boyce et al. 2002). Several models with differing sets of covariates are developed based on the *a priori* knowledge of the species in question. Models can then be evaluated against each other by means of an information theoretic approach, which compares model values of Akaike's Information Criterion (AIC; Burnham and Anderson 2002). The model in the set of candidate models with the lowest AIC value is considered the best model (Burnham and Anderson 2002). The difference in AIC values between the lowest scoring models is important, rather than the absolute size of a model's AIC value (Burnham and Anderson 2002). Models can be validated by testing their performance with other independent datasets, or by means of k-fold cross-validation (Boyce et al. 2002). k-fold cross-validation calculates a Spearman rank correlation coefficient (r_s) between k subsets of the data that were not used to generate the model. A model with a higher r_s value indicates a better model with higher predictive ability (Boyce et al. 2002). The best model is used in an RSF to predict the probability of use of a resource unit by an animal (Manly et al. 2002). The function can be geographically overlaid to provide a map of proportional probability of use. This map can be used to draw ecological conclusions about a species, related to home range, distribution, population, or response to an environmental change (Boyce and McDonald 1999, Boyce et al. 2002, Manly et al. 2002).

2.3. Reproductive Ecology of Moose

Moose reproduction includes a gestation period of approximately 7.5 months (Schwartz and Hundertmark 1993). The first puberty in female moose occurs between 16 to 28 months of age (Schwartz 2007). The mating season of most moose populations in Canada, the United States, and Europe occurs between in mid-September and mid-October (Sigouin et al. 1997).

In most moose populations, ovulation, conception, and pregnancy rates are not influenced by habitat quality, except in severely poor conditions (Schwartz 2007). Ovulation rates are consistently high in adult females varying from 71 to 100% (Schwartz 2007). Pregnancy or conception rates of adult females are consistently high throughout North America and average

84.2% (Boer 1992). In central British Columbia, pregnancy rates were 19% for yearlings and greater than 73% for females aged 2 to 10 years old, with fertility declining after age 13 (Heard et al. 1997). A pregnancy rate of 94% for females aged 2 to 11 years old was observed in the Saskatchewan boreal forest with 25% of pregnant moose carrying twins (Haigh et al. 1982). Foetal loss has been detected in wild ungulates, including moose (Testa and Adam 1998). Increasing rates of foetal loss occur in populations experiencing severe nutritional stress (Milner et al. 2003).

Reproductive success is defined as an individual's production of offspring per breeding event or lifetime. Reproductive success is also influenced by the number of offspring that an individual's own offspring produce (Moreno 2010). The ability to produce multiple offspring per breeding event has the potential to increase reproductive success. Moose can produce twins, but the rate of twinning varies considerably and is considered an indicator of nutrition, habitat quality, and carrying capacity (Gasaway et al. 1992, Franzmann and Schwartz 1985). Heard et al. (1997) found that twinning rates were related to kidney fat and mass, and age, and observed a twinning rate of 14% in females 2 years old and older. Twinning rates are highly variable across North America and have been recorded as high as 90% at Innoko River, Alaska to as low as <1% in Newfoundland (Gasaway et al. 1992). During a long-term study in Alaska from 1976-1985, 218 moose neonates, 61 calves 5 to 10 months of age, and 184 adults were captured and collared to better understand population ecology and dynamics (Ballard et al. 1991). The average age of the adult cow moose in this study was 7.7 years. Pregnancy and twinning rates averaged 81% and 38% respectively, and parturition occurred between May 18 and mid-June (Ballard et al. 1991). In northern New Hampshire, the rate of twinning was 20% and 10% in consecutive years (Scarpitti et al. 2005). Edwards and Ritcey (1958) found in British Columbia that twinning rates were not significantly different by age classes of females (2 to 9 years old) and over five years the average annual rate was 10%. Twinning rates in the range of 0 to 25% have been found in populations considered near or above their carrying capacity, while higher twinning rates suggest the population is below it's carrying capacity (Gasaway et al. 1992). Moderate productivity suggests a combination of adequate nutrition, and balanced adult sex ratios (Albright and Keith 1987). In a low-density moose population in central Labrador, twinning rates were low, suggesting low productivity habitat within the moose range (Jung et al. 2009).

The lifetime reproductive success (LRS) of an individual, or the number of young raised during its lifetime, is an indicator of the individual's contribution to the species and a measure of fitness (Rouan et al. 2009). LRS is difficult to determine as researchers rarely can study wild animals for their lifetime outside of captivity. Reproductive rates of individual moose vary from year to year. Reduced reproductive performance can be related to previous calving success and low body condition of female moose (Testa and Adams 1998).

The majority of moose calving occurs over a 19-day period from May 19 to June 8 (Sigouin et al. 1997). Over a four-year study, newborn moose calves were observed from May 10 to August 15 in northern New Hampshire (Musante et al. 2010). Testa et al. (2000a) found that 80% of moose calf births occurred between May 18 and June 3 in south-central Alaska from 1994 to 1997. The typical range of birth weight for moose calves is 12.7 to 16.4 kg (Keech et al. 1999, Schwartz 2007). Twin calves have a smaller birth mass individually than single calves (Schwartz and Hundertmark 1993). Female and male calf weights do not differ (Schwartz and Hundertmark 1993). Moose invest less energy into gestation compared to other ungulates, as the birth mass for moose calves is only half of that expected based on adult moose body size (Gaillard 2007).

Neonate survival often defines the maintenance and growth of ungulate populations (Duquette et al. 2014). The majority of cervids use three main anti-predation strategies for protecting their neonates: concealment or hiding, flight, and defense (Stringham 1974). Although young moose calves that are resting are sometimes separated from their dams when the adult is feeding, moose do not primarily use concealment or hiding and mainly rely on the defense of young against predators. Female moose with neonates have restricted movement and are usually observed resting with their young and feeding nearby (Lent 1974, Stringham 1974, Poole et al. 2007). Quite differently, white-tailed deer are a "hider" species, in which females travel up to 1 km from their young to feed and do not rest with their young during the hiding phase (Jackson et al. 1972, White et al. 1972). The hiding phase may last from birth to several weeks of age for white-tailed deer (Severinghaus and Cheatum 1956) and 18 – 20 days for elk (Altmann 1963). Moose calves often vocalized for their mother when separated (Stringham 1974), which would be detrimental to the young's survival if concealment or hiding was its main anti-predation strategy. Moose dams are often successful at protecting their young from wolves (*Canus lupus*),

whether by fleeing or standing together (Mech 1970). Moose calves are relatively safe during wolf attacks unless separated from the dam (Mech 1970).

The maternal bond between moose calves and their dam is very strong. Moose calves stay in proximity to their dam during their birth year, including during the mating season in the fall (Altmann 1958). Female moose stay very close to their young, especially in the first few days after parturition when they do not venture more than 5 m away (Altmann 1958, Stringham 1974). Young moose calves have poor mobility (Altmann 1958, Lent 1974). After 1 to 2 days post-partum, Stringham (1974) observed that moose dams remained close to their young, within 10 m, over the following week. Female moose occasionally separated from their young by approximately 40 m for over an hour, once the young had bedded down (Stringham 1974). Lent (1974) observed that while the calf is only a few days old, the dam will only travel up to 100 m away for a period of one or two hours.

Altmann (1958) describes a second period in the moose calf's life in which from 4–20 days old mobility improves, and the calf is able to follow its dam very closely. The foraging area of the dam is still considerably restricted (Altmann 1958). From 20 to 90 days old, the activity radius of the calf widens. Edwards (1983) found that in 106 observations of moose calves there were only 2 observations where a calf was seen by itself. When young are >14 days old, the dam will venture up to 100–200 m away from the resting young for up to 4 hours (Stringham 1974). The milk intake of a moose calf peaks around 23 days of age and then decreases with increasing calf age (Reese and Robbins 1994). Reduced milk intake corresponds with consumption of solid foods. Moose calves begin to forage by 2 to 3 weeks (14 to 21 days) of age and are weaned by five months of age (Stringham 1974, Schwartz 1992b).

Typically, female moose with young do not to associate with other moose (Hundertmark 2007). Pregnant moose cows aggressively chase off their yearling offspring before they are to give birth to a new calf in the spring (Altmann 1958). However, yearlings may remain near their dam and repeatedly attempt to reunite with her (Altmann 1958). If a female loses her newborn offspring, the dam may reunite with her previous year's offspring (Altmann 1958).

2.4. Moose Movement Rates and Habitat Selection around Parturition

Female moose movement rates in south-central Alaska increased significantly 2 days before parturition, then decreased for the next 9 days (Testa et al. 2000b). In this study, the

movement rates of the parturient female moose did not reach pre-parturition levels until calves were approximately 26 days old (Testa et al. 2000b). The median daily movement rate of female moose was 0.9 km from 8 to 2 days before calving and increased to 2.2 km for the 1 to 2 days before calving (Testa et al. 2000b). Poole et al. (2007) found that the hourly movements of all maternal female moose increased 2- to 3-fold during 1 to 4 days before calving and were generally directional. The female moose moved to calving areas that were outside of areas used during the 12 days before calving (Poole et al. 2007). Parturient females experience a decline in movement rates from May 1 to June 15, compared to non-parturient females (McLaren et al. 2017). Moose calving sites have been identified by movement rates of <100 m between hourly Global Positioning System (GPS) fixes for a period ≥3 consecutive days in May (Welch et al. 2000). Daily movement rates of females that lost their young were greater than rates by females that successfully raised young through to 45-days post-partum by 12% (Testa et al. 2000b). The movement rates of female moose with young slowly increases following parturition (Poole et al. 2007).

Other ungulate species demonstrate similar movement rate patterns related to parturition. Cervids commonly demonstrate marked declines in daily movement rates with decreases of >50% immediately following parturition (Long et al. 2009). In a study by Brook (2010), the parturition sites of elk were identified by a sudden drop in daily movement rates (<1 km/day). Movement rates increased the day after parturition (Brook 2010). DeMars et al. (2013) used three-day average movement rates, while Nagy (2011) used daily movement rates of female woodland caribou to estimate the timing of parturition. DeMars et al. (2013) found that not only parturition, but also neonate loss events, could be predicted by sudden and marked changes in female movement rates of woodland caribou. In the case of a caribou neonate dying, the movement rate of the caribou dam abruptly returned to pre-calving rates (DeMars et al. 2013).

Ungulates select parturition sites that minimize the predation risk of the young (and adult), while providing high quality forage to meet the increased nutritional demands caused by parturition and lactation (Edwards 1983, Bowyer et al. 1999, Poole et al. 2007). Parturient moose seclude themselves from all other moose, including their offspring from the previous year, before parturition occurs (Stringham 1974). The animal's home range and the availability of suitable habitat restricts where parturition sites can be selected (McGraw 2011).

Typical moose parturition sites in Wyoming have secluded shelter, available browse and are near water (Altmann 1963). In British Columbia, female moose selected parturition sites with higher forage, proximity to water and reduced tree density to enhance visibility (Poole et al. 2007). Poole et al. (2007) found that parturient moose did not consistently select for a specific vegetation or habitat type. However, all parturient moose avoided open cover types, regardless of whether open areas were natural or man-made from timber harvest operations (Poole et al. 2007). In contrast, McLaren et al. (2017), found that moose selected calving sites that were open rocky areas and open grass meadows. These open areas may have been selected because of increased wind providing relief from mosquitoes and black flies, or as a part of an anti-predator strategy (McLaren et al. 2017). These rocky open areas may allow for increased vigilance and maneuverability to defend calves from predators (McLaren et al. 2017). Female moose in Alaska selected for parturition sites with southerly slopes and high visibility, but selection of cover was highly variable and not towards any habitat type (Bowyer et al. 1999). Female moose also selected for higher forage quality, with willows being more than twice as abundant at parturition sites compared to random sites (Bowyer et al. 1999). Female moose did not select near human developments for parturition sites as a predator avoidance strategy (Bowyer et al. 1999).

In the boreal forest, female moose with young during the summer season select for wetlands which provide submerged and emergent aquatic vegetation (Parker 2003). Female moose demonstrate state-dependent habitat selection and avoid open, food rich areas in the first few months after calving (Bjørneraas et al. 2011). In contrast, males and females without offspring select for food rich open areas (Bjørneraas et al. 2011). During the summer season, reproducing females selected for forest cover compared to all other land cover types (Bjørneraas et al. 2011). In the eastern slopes of the Rocky Mountains, female moose used coniferous forest with high cover most often during the calving season, while using open low shrub vegetation with low cover the least (Parker and Gillingham 2007). Female moose inhabited the lowest elevations during the year in June, and after the calving season gradually moved upslope to higher elevations during the summer and fall (Parker and Gillingham 2007). In Alaska, lactating females spend more time closer to thick vegetative cover than non-lactating females (White and Berger 2001). In Minnesota, female moose with calves selected areas with more conifer and shrubland or conifer and regenerating forests compared to non-lactating females (McGraw 2011). In central Norway, in an area of forest and cultivated land, female moose with young

selected for forest over any other land cover type, including cultivated land (Bjørneraas et al. 2011). However, in autumn, females with and without young showed a high selection for cultivated land (Bjørneraas et al. 2011). Female moose with young limit their use of open habitats to periods around dusk, dawn and night, due to decreased human activity and a lower requirement for thermal cover (Bjørneraas et al. 2011). However, moose use open areas to travel between fragmented patches of habitat. Male ungulates are likely to choose habitats that maximize energy gains, while females with young select for habitat with protective cover as a priority over forage (Dussault et al. 2005a, Ciuti et al. 2006, Main 2008).

Methods to better understand ungulate parturition site selection and young mortality include the use of vaginal implant transmitters (VITs) and the subsequent capturing and GPS-collaring of neonatal ungulates (Patterson et al. 2013, DelGiudice et al. 2015, McLaren et al. 2017). VITs are radio-transmitters inserted in the ungulate's birth canal and designed to be expelled during parturition (Barbknecht et al. 2009, Tatman et al. 2011). Immediately following the expulsion of a VIT, the capture and collaring of the neonatal ungulate can occur. The wing width of VITs can determine the success of retention without physically harming the ungulate (Tatman et al. 2011). With a species, the desirable wing width of a VIT varies geographically (Tatman et al. 2011). Although effective, these methods are more invasive and GPS-collaring neonate moose calves increases the risk of calf abandonment (DelGiudice et al. 2015, DelGiudice et al. 2018). As well, researcher disturbance has the potential to change an animal's habitat selection. Considering the associated risks, these methods were not used in my study.

2.5. Predation and Mortality

Predation risk and avoidance influences the resource selection of prey species (Edwards 1983, Bowyer et al. 1999, Mao et al. 2005, Poole et al. 2007, van Beest et al. 2013). Survival objectives of moose include energy maximization and minimizing time spent foraging (Belovsky 1978). These objectives are particularly important for female moose with young that need to balance consuming enough energy for lactation with exposure to predators. In ecosystems with wolves ungulates avoid areas of high wolf density to reduce predation risk (Edwards 1983, Stephens and Peterson 1984, Ferguson et al. 1988, Dussault et al. 2005a, Fortin et al. 2005, Poole et al. 2007). All ungulate species must balance the use and risks of cover habitat with lower quality forage and more open areas with higher quality and quantity forage (Hirth 1977, Mech

1977). This is particularly true for female ungulates with vulnerable young post-parturition (Mech 1977, Mao et al. 2005, Pinard et al. 2012). Areas of high-human activity including urban development and transportation corridors displace predator species and can create spatial refuge for prey species including ungulates (Muhly et al. 2011).

In southeastern British Columbia, moose are the main prey of wolves and moose-kill sites were located farther from edges of regenerating forests than random sites (Kunkel and Pletscher 2000). Moose-kill sites were in areas of lower road density, higher wolf use, higher moose density, lower elevation, and lower hiding cover compared to random sites (Kunkel and Pletscher 2000). In Yellowstone National Park, elk resource selection was affected by the reintroduction of wolves (Mao et al. 2005). In summer, elk avoided wolves by selecting higher elevations, less open habitat, more burned forest, and steeper slopes when in areas of high wolf density compared to selection prior to wolf introduction (Mao et al. 2005). Caribou (*Rangifer tarandus caribou*) avoid wolf predation by selecting calving sites in upper slope positions and avoiding high road density areas (Pinard et al. 2012). However, this anti-predator strategy does not prevent black bear (*Ursus americanus*) predation (Pinard et al. 2012). Caribou select forest habitat with low lateral cover, allowing them to visually detect predators (Pinard et al. 2012). Female moose with young use human activity as a refuge from wolf predation, particularly in populations without human hunting (Stephens and Peterson 1984). Female and male moose express a differential response to human activity and housing density (Lykkja et al. 2009). Male moose stay closer to houses than females during low human activity periods and are more tolerant of higher housing densities and periods of high human activity (Lykkja et al. 2009).

Even when predators are not an immediate threat, the activity status of moose calves changes the behaviour of female moose (White and Berger 2001). Female moose with active calves spent 79.5% more time being vigilant for predators than those with inactive (recumbent) calves (White and Berger 2001). Further, females with inactive calves were less vigilant than non-lactating females (White and Berger 2001). The activity status of the calf also resulted in less foraging for females with active calves compared to females with inactive calves or without calves (White and Berger 2001).

Factors other than predation that affect moose densities and can cause mortality include malnourishment, long and severe winter conditions including deep snow, avalanches, human harvest, accidents and injuries, moose-vehicle collisions and entanglement by human

infrastructure (LeResche 1968, Ballard et al. 1991, Gasaway et al. 1992, Child 2007). Other sources of mortality include rapidly advancing forest fires, parasites and disease (LeResche 1968, Ballard et al. 1991, Gasaway et al. 1992, Child 2007).

2.5.1. Moose Calf Mortality

The moose calf is most vulnerable to the environment and predation when it is small and relatively weak as a neonate (LeResche 1968, Ballard and Van Ballenberghe 2007). Calf survival is lowest in the first month of life (Hauge and Keith 1981). The highest calf mortality rates often occur during the first five months post-parturition (LeResche 1968, Ballard et al. 1991, Ballard and Van Ballenberghe 2007). Before July 9th of each year, 96% of early mortality occurred in the study by Ballard et al. (1991). LeResche (1968) found that 56% of calf mortality occurred within the first 5 months after birth, and 26% of neonates were lost within 2 weeks post-parturition. In New Hampshire, 76% of calf mortality during the summer season occurred ≤ 28 days post-partum (Musante et al. 2010). In northern New Hampshire, annual calf survival for calves 0–2 months old in a stable moose population averaged 0.71 over 4 years with yearly averages ranging from 0.55 to 0.81 (Musante et al. 2010). For moose calves six to twelve months old (i.e., from November to May), the largest single source of mortality (79%) was starvation during a severe winter in Alaska (Ballard et al. 1991).

Moose calf survival varies and is linked to predator densities, as well as the date of individual calf births (Testa 2002). Young ungulates are especially vulnerable to predation and females with young respond differently to predation risk. Earlier-born moose calves are more likely to escape predation and survive (Testa 2002). Predation is often the primary cause of moose calf mortality and has been shown to account for up to 83% of mortalities (Ballard et al. 1991, Gasaway et al. 1992). The main predators of moose calves in North America are wolves, black bears, and brown bears (*Ursus arctos*) (Ballard and Miller 1990, Ballard and Van Ballenberghe 2007, Keech et al. 2011). Known predators of moose calves in New Hampshire include black bear, coyote (*Canis latrans*), and bobcat (*Lynx rufus*) (Musante et al. 2010). Where their distribution overlaps, cougars (*Puma concolor*) also kill moose calves and adults (Knopff et al. 2010). In Manitoba, the removal of black bears resulted in significant increases in moose calf survival (Kotchorek 2002). In east-central Saskatchewan, an estimated 40–48% of moose calves are killed by black bears (Stewart et al. 1985). Coyotes may be predators of neonate moose

calves depending on the defensive nature of the moose cow. In Alaska, Ballard et al. (1991) recorded the death of a moose calf due to coyote predation. In Ontario, Benson and Patterson (2013) documented four cases of eastern coyotes or eastern coyote x wolf hybrids (*Canis lycaon*) killing young moose ≤1.5 years old.

One of the lowest calf mortality rates in North America (16%) was observed in an area without wolves or brown bears, and with low black bear presence, approximately 100 km north of Edmonton, Alberta (Rolley and Keith 1980, Mytton and Keith 1981, Ballard and Van Ballenberghe 2007). In south-central Alaska, Testa et al. (2000a) found the rate of moose calf survival from parturition to the end of July was 0.27 ± 0.03 SE, with the daily rate of mortality decreasing with age during this period. Mean annual survival rate was slightly lower at 0.22 ± 0.03 SE (Testa et al. 2000a). In Alaska, mortality rates for twin and single calves are not significantly different and the number of calves (twin or single) does not influence calf survival (Ballard et al. 1991, Testa et al. 2000a). However, twins often die together within 15 days post-parturition, but thereafter die independently (Testa et al. 2000a). Survival of twin calves up to 15 days of age was 0.50 ± 0.06 SE (Testa et al. 2000a). This suggests that predators that find the calves during the 0 to15 day period were able to kill both calves (Testa et al. 2000a). Franzmann et al. (1980) observed an average mortality rate of 58% for moose calves during two summers in Alaska.

In the long-term study by Ballard et al. (1991), survival of calves during the first 5 months of age averaged 39%, with twin and single calves having similar survival rates. In this study predation accounted for 83% of the total mortality among moose neonates in 1977-1979 and 1984. Ballard et al. (1991) observed that 96% of calf mortality occurred from birth to 6 weeks of age with brown bears accounting for 73% of that mortality. In this study, annual calf survival rates averaged 34% and 31% for females and males, respectively. In east-central Alaska, up to 70% of moose calves died from predation before 11 months of age with 52% of calves killed by grizzly bears, 12–15% by wolves and 3% by black bears (Gasaway et al. 1992).

Despite normal pregnancy rates and negligible predation in a Norwegian moose population, prenatal, neonatal and over-summer calf mortality reduced autumn recruitment rates to 23 – 69% (Milner et al. 2013). Decreased early survival of calves was attributed to poor winter nutritional conditions that create a reproductive carry-over effect (Milner et al. 2013). Other than predation, other documented sources of moose calf mortality include complications at birth,

exposure, drowning, abandonment, injury inflicted by the dam, disease, entrapment by vegetation, entanglement by human infrastructure, and accidental mortality from falls and subsequent injuries (LeResche 1968, Peterson 1977, Gasaway et al. 1992, Child 2007).

2.5.2. Adult Mortality

After reaching a year or more in age, female moose typically have high annual survival rates than males (Peterson 1977). Ballard et al (1991) observed annual survival rates of averaged 94.8% for female yearlings and 95% for adult female moose. The lowest annual yearling survival was 75%, with causes of mortality being starvation and wolf predation (Ballard et al. 1991). In Alaska, annual survival rates of adult and yearling males were 75.4 and 90.9% (Ballard et al. 1991).

Predation of adult moose occurs from wolves and grizzly bears (Ballard and Van Ballenberghe 2007). Increased age influences adult vulnerability to predation, with conditions such as malnutrition, arthritis, broken bones, and jaw necrosis contributing to mortality (Peterson 1977). The mortality rate of adult female moose increases between late-pregnancy and immediately post-partum, which is partially due to predation by brown bears and wolves (Poole at al. 2007). In east-central Alaska, human harvesting followed by predation, are the primary causes of yearling and adult moose mortality (Gasaway et al. 1992). Of adult mortality, 89% was caused by grizzly bears and wolves (Gasaway et al. 1992).

Other causes of adult mortality include males succumbing to antler wounds or locked antlers with another male and drowning (Gasaway et al. 1992). Heavy loads of parasites contribute to vulnerability and mortality in moose (Peterson 1977). Arthritis and jaw necrosis are found in moose >7 years of age (Peterson 1977). Adult males at any given age have a higher mortality rate than females, likely due to the stress of low nutrient consumption and high energy use during the annual fall mating season (Peterson 1977). Additionally, human hunting is an important cause of moose mortality in areas where hunting the species is legal.

2.5.3. Human Hunting of Moose and Non-Lethal Disturbances

Moose are considered a desirable game animal for hunting. Human hunting of moose and other ungulate species occurs mainly in the fall season. However, Indigenous or subsistence hunting and illegal hunting occur throughout the year. Areas with fragmented patches of cover

act as population sinks for moose because of the relative ease in hunting these large and highly visible ungulates (Woodroffe and Ginsberg 1998).

Dense road networks associated with active forest management and agricultural activities may result in greater predator and hunter access to moose (Telfer 1995). Hunting pressure has been found to change the behaviour of ungulates similar to pressure from predators (Stankowich 2008). Non-lethal human disturbances, such as hiking and snowmobiling, result in increased movement rates, diurnal activity ranges, and moose vacating areas (Neumann et al. 2011). Likely, the impact of a disturbance on moose reflects the type and severity of the disturbance. In a study by Neuman et al. (2011), moose movement rates were elevated for 1 hour following a hiking disturbance and 2 hours after a snowmobile disturbance.

Female ungulates or groups with young demonstrate greater flight responses to disturbances than adult-only groups (Stankowich 2008). Ungulates in open habitats have greater perception of risk associated with disturbances (Stankowich 2008). In hunted populations, ungulates appeared more fearful at dusk and dawn compared to other times (Stankowich 2008). However, in areas with higher rates of exposure to human activity ungulates show reduced flight responses (Stankowich 2008). In Alaska, human hunting is the largest source of adult male moose mortality (Ballard et al. 1991). In Sweden, between 40 and 60% of the adult moose population is harvested annually (Cederlund et al. 1987).

It is evident through moose hunting quotas that moose have expanded southward within Saskatchewan. Moose hunting quotas are available in WMZs that previously had insufficient moose populations to support hunting. Prior to 2009, hunting licences for moose in my study area were not available through the Saskatchewan Big Game Draw (Saskatchewan Ministry of Environment 2014, unpublished data). In 2009, Wildlife Management Zones 22, 23, and 29 had hunting quotas of 25, 50, and 50 for either-sex moose respectively. In 2014, hunting quotas for either-sex moose increased in these zones to 50, 60, and 40 licences in Zone 22, 23, and 29 respectively (Saskatchewan Ministry of Environment 2014, unpublished data). In 2009, an antlerless moose hunting quota first became available for Zone 23 with 100 licenses. In 2010, the first antlerless moose quota for Zone 22 was 25 licenses. In 2011, 25 antlerless moose licenses were available in Zone 29 for the first time (Saskatchewan Ministry of Environment 2014, unpublished data). In 2014, antlerless moose quotas within the study area increased with Zones 22, 23, and 29 having quotas of 95, 100, and 59 licenses, respectively. In 2014, antlerless moose

quotas decreased to 40 licences in each of Zones 22, 23, and 29 (Saskatchewan Ministry of Environment 2014, unpublished data). Including all of Saskatchewan, the overall Saskatchewan Big Game Draw hunting quotas for moose was set at 4,210 licenses in 2009, 6,000 licenses in 2013, and increased to 6,020 licenses in 2014 (Saskatchewan Ministry of Environment 2014, unpublished data). In 2019, the tentative hunting quotas for all moose in Saskatchewan was set at 5,060 licenses, representing a 15.95% decrease in licenses from 2014 (Figure 2.2). In 2014, WMZs 3 and 9 were the only two Zones in Saskatchewan that did not have hunting quotas for moose, both located in the southwestern portion of the province (Saskatchewan Ministry of Environment 2014, unpublished data). Other types of licenses, such as regular season licenses (i.e., the hunter does not have to be drawn to buy a license), Canadian Resident Draw licenses, and Guided licenses, are not available for moose within the WMZs overlapping my study area (Government of Saskatchewan 2014). Additional moose are likely harvested within my study area by Aboriginal and Metis hunters. However, hunting by Aboriginal and Metis hunters is not regulated or currently recorded and the number of harvested moose is difficult to estimate.

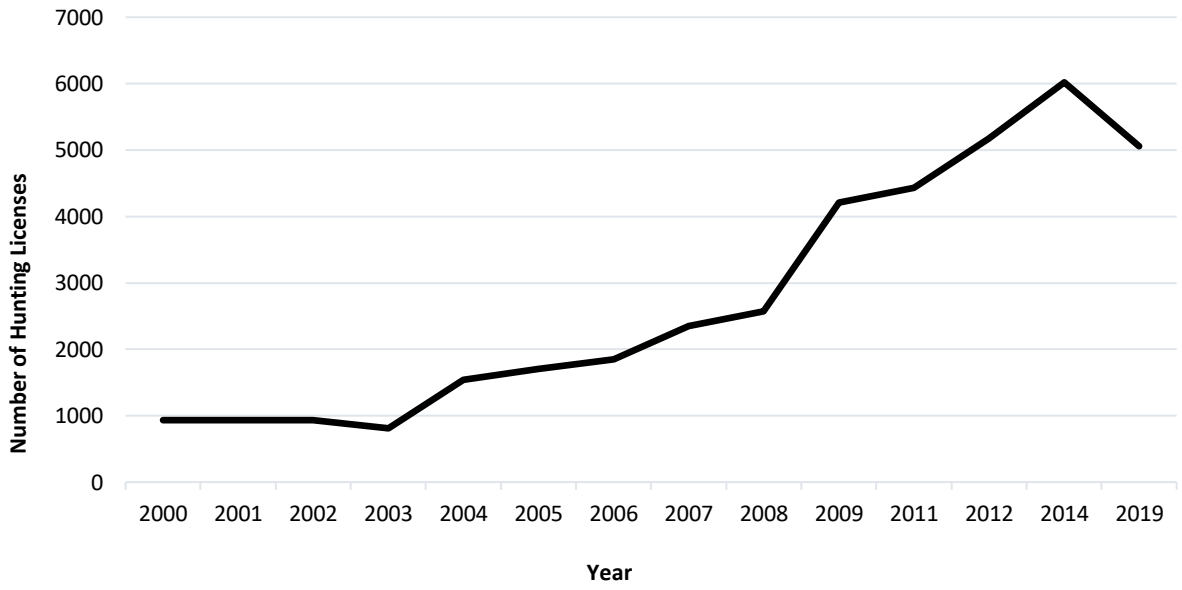

Figure 2.2 The number of Saskatchewan Big Game Draw moose hunting licenses available during select years from 2000 to 2019.

2000 to 2014 data - Saskatchewan Ministry of Environment 2014 unpublished data

2019 data - Government of Saskatchewan 2019b

2.6. Movements, Home Range and Site Fidelity

The following provides a review of several studies with home range results from moose. However, comparisons of home range study results are not always possible due to the many different estimation methods for home ranges, such as minimum convex polygons or kernel utilization distributions (Hundertmark 2007). Across the global distribution of moose, the home range sizes of moose vary considerably and are likely influenced by habitat quality, and other factors (Snaith and Beazley 2004). A home range consists of the area within which an animal moves in when performing its normal activities (Harris et al. 1990). The time period over which a home range is determined is one of the most important parameters to define a home range (Morris 1988). Seasonal divisions rather than an arbitrary division of time should be used to prevent misinterpretation or unintentionally hiding important changes in behaviour (Harris et al. 1990). Animals are unlikely to uniformly use their home range, and most have preferred areas defined by a high proportion of used locations (Harris et al. 1990).

Moose populations are often considered either migratory or sedentary, where migratory populations move annually between summer and winter home ranges and sedentary populations use summer and winter home ranges that overlap or are located adjacent to each other. In Mountainous areas, winter ranges are usually associated with lower elevation (Hundertmark 2007). In Maine, where moose are mainly sedentary, winter home ranges are within or adjacent to summer home ranges (Crossley and Gilbert 1983). Female moose in central Sweden are mainly migratory and have been observed migrating northward 14 to 60 km in the spring from winter to summer home ranges (Sandegren et at. 1982). In Alaska, individual moose are migratory or sedentary, and distances between winter and summer home ranges of migratory moose ranged between 16 and 93 km (Ballard et al. 1991). Phillips et al. (1973) found that 20% of moose in Minnesota were migratory, with migration distances ranging from 14.4 to 33.6 km. Ballard et al. (1991) identified three periods of distinct movement, which were in late autumn to winter home ranges, in spring to summer home ranges and during the rut to seek out mates. Despite the distance travelled by migratory moose between seasonal home ranges, Ballard et al. (1991) did not observe a difference between the winter home range sizes of migratory and sedentary moose in Alaska. This is potentially due to winter snow depth restricting movement for all moose. Summer and annual home ranges were larger for migratory moose (Ballard et al.

1991). In Alaska, the onset of migration to winter home ranges often occurs after a significant snowfall (Ballard et al. 1991).

During the mating season or rut, the movement rates of male moose increase while the movement rates of females decrease (Phillips et al. 1973, Garner and Porter 1990). Movement rates of moose tend to be greatest in the summer months and smallest during winter (Phillips et al. 1973, Hundertmark 2007). Phillips et al. (1973) observed a daily average movement date of 0.9 km for moose in Minnesota. Daily movement patterns differ between the sexes (Hundertmark 2007). Prior to the rut, male moose move equally during the day and night, while early in the rut males moved more during the day, and later in the rut males moved more at night (Phillips et al. 1973). Female moose moved more at night during early summer and the rut, possibly as an anti-predator strategy to protect their offspring in the early summer and then to avoid human hunting pressure during the rut (Phillips et al. 1973).

Seasonal ranges of female moose were typically smallest during the calving season at 18 km^2 and were up to 7 times larger during the summer season (Parker and Gillingham 2007). Several other studies have observed that female moose with young have smaller home ranges than other age/sex classes of moose (LeResche 1974, Ballard et al 1991, van Beest et al. 2011). Mean winter to spring and summer to fall home ranges for moose were 12.3 km^2 and 15.2 km^2 for males, and 21.2 km^2 and 16.3 km^2 for females (Van Dyke et al. 1995). In Sweden, the mean home range of adult female moose was 12.6 km^2, with summer home ranges typically being twice as large as winter home ranges (Cederlund and Okarma 1988). In Alberta, moose summer home ranges are >20 km^2 (Hauge and Keith 1981). In Nova Scotia, the mean sizes of winter, summer, and fall home ranges for female moose were 20.3, 23.9, and 22.7 km^2, with a mean annual home range of 41.9 km^2 (Parker 2003). In south-central Saskatchewan, female moose had mean summer and winter home ranges (95% kernel home range) of 34.6±19.4 km^2 and 91±130.9 km^2, respectively (Brook et al. 2016). Summer home ranges ranged from 6.3 to 78.8 km^2, while winter home ranges ranged from 6.8 to 454.1 km^2. Annual home ranges were a mean of 227.7 km^2 and ranged in size from 33 to 1,373 km^2 (Brook et al. 2016).

Site or home range fidelity refers to the return of an individual animal to an area for a season, parturition, or other important time period (van Beest et al. 2013). Adult moose tend to use the same home range areas throughout their lives (LeResche 1974, Cederlund and Okarma

1988, Ballard et al. 1991). However, in Alaska, one adult female moose (1% of study animals) relocated 177 km from her original home range (Ballard et al. 1991). Van Dyke et al. (1995) found that female moose had strong site fidelity to both seasonal and annual home ranges each year with little variation in activity centers. However, home range fidelity varies widely. Cederlund et al. (1987) found that consecutive summer home ranges in female moose overlap 1 to 100%. In habitat fragmented by agricultural activities, low overlap was observed between moose summer and winter ranges in Saskatchewan (Brook et al. 2016).

2.6.1. Dispersal

Moose that disperse are predominately juvenile males, although other age and sex groups disperse as well (Hundertmark 2007). The dispersal of young affects population expansion, potential collision risk, habitat selection, reproduction and population density. Natal dispersal of offspring from the dam's home range can be a partial or complete dispersal and may occur over several seasons (Ballard et al. 1991). Male offspring are more likely than female offspring to disperse from their dam's home range (Ballard et al. 1991). Female moose as yearlings and later as adults continue to stay relatively close to their mother's home range during consecutive summers (Cederlund et al. 1987). From mid-June to the end of August the previous year's offspring stayed a relatively constant 1.5 to 2.0 km from the adult female moose (Cederlund et al. 1987). The density of moose likely acts as an important factor in dispersal with higher densities resulting in higher dispersal rates, and dispersing moose moving from high to low density areas (Gasaway et al. 1980, Ballard et al. 1991). In Alaska, areas that moose disperse to have greater hunting pressure and lower bull densities than the areas where dispersing moose had been raised (Ballard et al. 1991). Further, the size of the offspring's newly formed home range was positively correlated to the size of the dam's home range (Ballard et al. 1991). However, male offspring had larger seasonal and annual home ranges than female offspring (Ballard et al. 1991). In Quebec, dispersal movements to new home ranges were most common in yearlings (72% of incidences) with individuals dispersing up to 50 km (Labonté et al. 1998).

2.6.2. Parturition Site Fidelity

Reproductive success may influence female moose fidelity to parturition sites. Parturition sites in successive years were closer together if at least one calf survived to the end of July (Testa

et al. 2000a). In an area that lacks natural predators of moose in Norway, female moose expressed fidelity to parturition sites (Tremblay et al. 2007). Low calf mortality in this area made it difficult to statistically detect if fidelity was influenced by the loss of a calf (Tremblay et al. 2007). In Ontario, distances between successive parturition sites varied from 56 m to 12.32 km (Welch et al. 2000). When a calf was raised successfully, female moose were more likely to use a site closer to the previous parturition site than females who were unsuccessful in raising a calf (Welch et al. 2000).

2.7. GPS-collar Telemetry Data

Wildlife collars with GPS technology are very useful in automatically providing a large amount of location data at a relatively low-cost per animal location. Compared to very high frequency (VHF) radio telemetry collars, where field triangulation is necessary to obtain occupied animal locations, GPS-collars have relatively low labour costs with location points being downloaded automatically or stored on the collar. However, as with all technologies, errors can occur. Missing or inaccurate locations are the two main types of errors that can occur in GPS location data (Graves and Waller 2006, Lewis et al. 2007). Accuracy of a collared animal's location depends on the number of satellites from which the GPS unit on the collar receives signals. Location fixes that are two-dimensional are often less accurate than 3-dimensional fixes, which are estimated from 3 rather than 4 satellites (Lewis et al. 2007, Jiang et al. 2008). Missing location fixes usually occur when the GPS unit receives signals from <3 satellites. Telemetry data should be examined prior to analysis using screening procedures that compromise between data accuracy and data loss (Bjørneraas et al. 2010).

2.8. Development of Methodology

2.8.1. Capture and Collaring

Although GPS collar technology is expensive compared to Very High Frequency (VHF) radio collars, it allows for the collection of many locations of radio-collared animals without disturbing the study animals and possibly biasing their resource use. The collars used in my study also have a VHF signal that allows the animal to be found with a hand-held receiver by researchers on the ground or while flying in an airplane. When using GPS collars that do not

transmit positional data, but instead store it on-board within the collar, there are inherent risks such as mechanical collar failures or loss of the animal and/or the collar (Dettki et al. 2004).

Capture and collaring moose with chemical immobilization results in mortality rates between 6% and 19% (Roffe et al. 2001). One study found significant mortality with 9 of 11 captive moose dying when given a combination of carfentanil and xylazine (Kreeger 2000). The cause of the mortalities was related to xylazine, which is a sedative drug that increases the risk of bloat, regurgitation and aspiration of rumen contents (Arnemo et al. 2003). However, Roffe et al. (2001) immobilized 41 free-ranging female moose with a combination of xylazine and carfentanil without mortality. The authors attributed their success in capture and the recovery of moose to using low-stress techniques including quietly processing the blind-folded moose. Roffe et al. (2001) found that capture-related mortality occurred when the body condition of female moose was below a threshold. Chemical immobilization was not used in my study due to the increased mortality risk to moose. Additionally, I wanted to prevent recovering moose that had been chemically immobilized from inadvertently crossing highways and roads, which could result in MVCs.

Carpenter and Innes (1995) observed a mortality rate of less than 1%, when using net guns fired from helicopters to capture moose, with cervical fractures as the most common cause of capture mortality. Ideal conditions for net gun capture of moose occur in winter to prevent heat stress and with adequate snow depth to slow the running animal (Carpenter and Innes 1995). Unlike other ungulates such as elk or deer, moose are usually solitary animals and more tolerant of humans (Roffe et al. 2005). The solidary nature of moose generally results in successful capture when using net guns fired from helicopters. Arnemo et al. (2003) suggests that chemical immobilization from a helicopter in winter is the best capture method for moose, but that a mortality rate greater than 2% during chemical immobilization is unacceptable. Consequently, the capture of moose in my study was completed during periods with adequate snowfall using net-guns fired from a helicopter.

2.8.2. Spatial Autocorrelation

Spatial autocorrelation is the degree of interdependence between variables and its presence violates the assumption that samples or sites are spatially independent. Animal movements are inherently highly autocorrelated (Cushman 2010). An animal's next location has

to be available from its current location, which results in autocorrelated locations for long time durations (Cushman 2010). In the spatial analysis of animal observations, temporal autocorrelation of locations leads to underestimation of home range size (Swihart and Slade 1985, White and Garrott 1990). Subsampling to achieve statistical independence also results in substantial underestimation of range size and rates of movement (Rooney et al. 1998).

A priori, there is no way to determine what the time duration between successive locations to achieve independence will be (Harris et al. 1990). However, filtering or subsampling data to achieve statistical independence results in information loss. Further, even long sampling intervals do not guarantee independence (Cushman et al. 2005). Legendre (1993) and Legendre and Fortin (1989) argue that spatial autocorrelation is an informative ecological parameter that reveals scales and patterns of ecological processes. Autocorrelation in a data set should be interpreted with an ecological perspective (Hundertmark 2007). Reducing the frequency of location points through subsampling allows the data to appear statistically independent and not show significant autocorrelation (Fieberg et al. 2010). However, sparse sampling of an autocorrelated data stream does not remove the effect of autocorrelation from the data, rather it only reduces the ability to detect it (Fortin and Dale 2005). Bahn and McGill (2013) state that spatial autocorrelation is less of a concern when analysing resource selection within a region rather than using the model to predict into new geographic areas. Based on the current knowledge of spatial autocorrelation in the literature, I did not remove location data or subsample data for the purpose of analysing female moose resource selection within my study area.

2.8.3. Determining Pregnancy

Progesterone levels in blood serum have been successfully used to detect pregnancy in moose (Haigh et al. 1982, Testa and Adams 1998, Poole et al. 2007, Milner et al. 2013). This method has also been used to detect pregnancy in caribou (Demars et al. 2013). Pregnancy can be confirmed by observing the female with young (Demars et al. 2013). In Saskatchewan, rectal palpation has also been used to diagnosis pregnancy in moose in March (Haigh et al. 1982). In March, moose progesterone levels range from 5.4 to 11.5 ng/ml in pregnant moose, 0.42 ng/ml in a non-pregnant female and 0.15 ng/ml in a male (Haigh et al. 1982).

2.8.4. Hypothesis-testing Framework

The information-theoretic approach used in my study is suitable for complex ecological studies examining multiple working hypotheses (Chamberlin 1965). Multiple working hypotheses means that it is possible for more than one hypothesis to be simultaneously true (Chamberlin 1965). This approach is commonly used in the disciplines of psychology, statistics, and wildlife biology (Elliott and Brook 2007). Unlike techniques of null-hypothesis testing, this approach is well suited to ecological research where a true control and treatment design is not possible, particularly when analyzing habitat selection of wildlife outside of captivity (Johnson and Omland 2004, Dochtermann and Jenkins 2011). Researcher bias is reduced by allowing numerous potential explanations to be explored by simultaneously evaluating a set of competing hypotheses, as this approach circumvents the natural tendency of investigator attachment to a single hypothesis (Elliott and Brook 2007).

Chapter 3: Habitat selection by Parturient and Post-parturient Adult Female Moose (*Alces alces*) on the Canadian Prairies

3.1. Introduction

Historically, moose in Saskatchewan (SK), Canada, were broadly distributed across the boreal forest, the Aspen Parkland (Berg and Phillips 1974, Reeves and McCabe 2007), and the Cypress Upland Ecoregion (Acton et al. 1998). Moose Mountain and Cypress Hills Provincial Park in southeastern and southwestern Saskatchewan respectively, are 'islands' of forest habitat that support resident moose (Karns 2007). Recently, moose have expanded their range southward to encompass their pre-European range, which coincides with the Aspen Parkland Ecoregion (Berg and Phillips 1974, Reeves and McCabe 2007). In Saskatchewan, moose have expanded even further south into agriculture-dominated landscapes (i.e., farmland) within the Moist Mixed Grassland and Mixed Grassland Ecoregions (Laforge et al. 2016). Moose inhabiting the agricultural areas of Saskatchewan represent an expanding population, which prior to this research, has been largely unstudied with few exceptions (see Laforge et al. 2016). It is likely that the southward range expansion of moose in Saskatchewan began between 1999 and 2006, approximately 14 to 21 years ago, based on Saskatchewan moose range maps (Arsenault 2000, 2009).

While moose have expanded southward into the Canadian Prairies in Saskatchewan there has been a population decline in northern Saskatchewan in the boreal forest. Since 2016, the boreal forest moose population continues to decline with winter population estimates 30 to 50% below the long-term average (Saskatchewan Ministry of Environment 2017, Government of Saskatchewan 2018a, 2018b). Obtaining reproductive parameters and determining habitat selection in this expanding moose population could provide valuable insights for the management and conservation of moose populations that are in decline throughout North America. Jurisdictions in North America experiencing moose declines include Alaska (Timmerman 2003), Manitoba, Ontario, (Ontario Ministry of Natural Resources and Forestry 2016), Minnesota (Murray et al. 2006, Wildlife Management Institute 2014, Morse 2015, Minnesota Department of Natural Resources 2016), New Hampshire, Montana, Wyoming (Wildlife Management Institute 2014, Morse 2015), and Nova Scotia (Pulsifer and Nette 1995,

Parker 2003, Broders et al. 2012), as well as three regions within British Columbia (British Columbia Ministry of Forests - Lands and Natural Resource Operations 2014).

Habitat selection of moose has been thoroughly investigated in boreal forest populations, but very little is known about habitat selection by moose in an agriculture-dominated landscape. Habitat selection can be positive or negative, positive referring to a component being used more than its availability (i.e., selected for), and negative selection meaning using a component less than its availability (i.e., selected against). In my study area in Saskatchewan, south of the Aspen Parkland, there is very limited forest cover with approximately 86.9% or 481,593 hectares (ha) of annual cropland and grassland combined (Agriculture and Agri-Food Canada [AAFC] 2014a). Variation in habitat quality could affect habitat selection patterns by moose and may be key factor in the reproductive success of this expanding moose population. In most moose populations, ovulation, conception, and pregnancy rates are not influenced by habitat quality, except in severely poor conditions (Schwartz 2007). Pregnancy or conception rates of adult females are consistently high throughout North America with an average of 84.2% (Boer 1992). In the boreal forest of Saskatchewan, a historical estimate of pregnancy rate of 94% was recorded, along with a 25% twinning rate (Haigh et al. 1982).

Habitat quality differs among habitats that moose encounter, and this affects patterns of habitat selection. The quality of selected habitats can influence calf survival. Neonatal ungulates are very vulnerable to the environment and predation (LeResche 1968, Ballard and Van Ballenberghe 2007). Before July 9th of each year, 96% of early moose calf mortality occurred in the study by Ballard et al. (1991). LeResche (1968) found that 56% of moose calf mortality occurred within the first 5 months after birth, and 26% of neonates were lost within 2 weeks post-parturition. Parturient ungulates select parturition sites that minimize the predation-risk of the young (and adult), while providing high quality forage to meet the increased nutritional demands caused by lactation (Edwards 1983, Bowyer et al. 1999, Poole et al. 2007). Altmann (1963) described typical parturition sites as having secluded shelter, available browse and being near water.

Many aspects of the ecology of this agricultural moose population warrant study to aid in developing appropriate management strategies. To support effective management of farmland moose during a time when many moose populations are experiencing marked declines, I examined reproductive success, and the selection of parturition sites and post-parturition habitat,

a period when young calves are most vulnerable. My objectives were to (1) determine reproductive measures, such as pregnancy and twinning rates, of adult female moose in farmland areas of Saskatchewan, (2) characterize the calving period of this moose population and estimate specific parturition sites of individual females, (3) quantify the strength of selection for specific habitat types by female moose for use as parturition sites, (4) estimate home range size for post-parturient female moose with young, and (5) quantify resource selection by adult female moose during the period of 20 days post-parturition when calves are most vulnerable.

3.2. Study Area

The study area encompasses approximately 10,737 km^2 of agriculture-dominated landscape in south-central Saskatchewan (SK), Canada (51.16° N, 105.58° W; Figure 3.1). The study area is centered along Provincial Highway 11 from the town of Dundurn, SK, near the study area's northern extent, to the town of Chamberlain, SK. The town of Tuxford, SK is located near the study area's southern boundary. The study area includes WMZs 22, 23, and a portion of 29 and 30, which were established by the Saskatchewan Ministry of Environment (Government of Saskatchewan 2014). These zones are recognized as having increasing numbers of moose over the 5-year period of 2006 to 2011 (Saskatchewan Ministry of Environment 2013). Dundurn is located at UTM Coordinates NAD83 Zone 13U 396012 m E 5740952 m N with an elevation of approximately 560 m, while Tuxford, SK is located at UTM Coordinates NAD83 Zone 13U 458739 m E 5602857 m N with an elevation of approximately 632 m.

Figure 3.1 Study area located between Saskatoon and Tuxford, Saskatchewan. Highway #11 is indicated by the red line extending northwest to southeast through the study area.

The majority of the study area is located within the Moist Mixed Grassland Ecoregion of Saskatchewan (Acton et al. 1998). A small area in the southwest extent of the study area is located within the Mixed Grassland Ecoregion (Acton et al. 1998). The study area occurs in the South Saskatchewan and Qu'Appelle drainage basins and has a sub-humid continental climate where the summer season is brief with an average 110 frost-free days (Acton et al. 1998). The climate of the Moist Mixed Grassland Ecoregion is typically cooler and moister than the Mixed Grassland Ecoregion to the southwest, and warmer and slightly drier than the Aspen Parkland Ecoregion to the north and east. Approximately 383 mm of annual precipitation and 240 mm of that total occurs as rainfall between May and September in the Moist Mixed Grassland Ecoregion (Acton et al. 1998).

Saskatoon is the largest Saskatchewan city (Population: 222,246 [Statistics Canada 2012]) located on the northern extent of the Moist Mixed Grassland Ecoregion. Saskatoon is located approximately 30 km northwest of the northern extent of the study area. Moose Jaw is located near the southern edge of the Moist Mixed Grassland approximately 20 km southeast of the southern extent of the study area. Saskatoon and Moose Jaw are the two closest locations to the study area where long-term climate data have been collected (Table 3.1; Table 3.2).

Table 3.1 Temperature at two Saskatchewan cities near the study area.

City	Long-term Temperature Data (1981 to 2010)[1]			Temperature Data (2012 to 2014)[2]	
	January Average	July Average	Annual Daily Average	January Average	July Average
Saskatoon	-13.9ºC	19.0ºC	3.3ºC	-13.8ºC	19.0ºC
Moose Jaw	-12.3ºC	19.3ºC	4.2ºC	-11ºC	18.6ºC

[1] Government of Canada 2014
[2] Government of Canada 2016

Table 3.2 Precipitation at two Saskatchewan cities near the study area.

City	Annual Average Precipitation Data[1]				
	2012	2013	2014	2015[2]	Long-term Annual Average (1981 to 2010)
	(mm)				
Saskatoon	465.2	246.8	364.9	339.5	340.0
Moose Jaw	373.6	358.8	561.3	285.7	365.0

[1] Government of Canada 2016
[2] Precipitation data are unavailable for Moose Jaw, SK, in April and May 2015.

The study area occurs in the Dark Brown soil zone with Chernozemic soils being the most common (Acton et al. 1998). Level to gently undulating glaciolacustrine and glacial till plains occur in the study area and this gentle topography has allowed for the mass conversion of land to agricultural crop production. Several valleys and coulee complexes occur within the study area and provide a slight change in elevation and natural vegetation communities, including the valleys associated with Blackstrap Lake, east of Dundurn, SK and the Arm River, east of Provincial Highway 11 from Davidson to Chamberlain, SK, within the study area.

Agricultural crop production is the primary land use with over 80% of the ecoregion under cultivation (Acton et al. 1998). According to the Agriculture and Agri-Food Canada annual land cover map (Agriculture and Agri-Food Canada 2013, 2014a) based on 30 m spatial resolution Landsat imagery from 2013 and 2014, approximately 817,656 hectares (ha) or 70% of the study area is used as annual cropland. The amount of annual cropland within Saskatchewan fluctuates with global and local demand and market prices of agricultural commodities (e.g., crops and beef), as well as with changes in land tenure. In Saskatchewan, agricultural crop production is dominated by three main crop types: cereals including wheat (31%) and barley (6%), oilseeds (28%) including canola and flax, and pulse crops (9%) including field peas, chick peas and lentils (Statistics Canada 2011). Irrigation is used in the production of agricultural crops in proximity to the South Saskatchewan River, Lake Diefenbaker, and the Qu'Appelle River. The majority of the study area is in the Lake Diefenbaker Development Area, which has 9 irrigation districts and over 100,000 acres producing crops under irrigation (Saskatchewan Ministry of Agriculture 2003). Other land uses include the seeding of introduced agronomic grasses and forbs for livestock grazing (pasture) and hay production on approximately 139,696 ha or 11.8% of the study area (Agriculture and Agri-food Canada 2014a).

In natural areas, tree and shrub cover is limited to mesic sites in native grassland used for livestock grazing, and riparian areas surrounding wetlands that have not been cleared or drained within cropland. Although tree and shrub cover is generally low, the dominant tree species within the study area is trembling aspen, but other species are present in valleys and coulees include Manitoba maple (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), balsam poplar (*Populus balsamifera*), and paper birch (*Betula papyrifera*). Native and non-native tree and shrub species that are commonly planted in yard sites or shelterbelts within the study area include caragana (*Caragana arborescens*), common lilac (*Syringa vulgaris*), Colorado blue spruce

(*Picea pungens*), hybrid popular (*Populus* hybrids), Manitoba maple, and Scots pine (*Pinus sylvestris*). Shrubs commonly found in native grassland include rose species (*Rosa* spp.), western snowberry (*Symphoricarpos occidentalis*), and wolf-willow (*Elaeagnus commutata*). In valleys and coulees within the study area, common trees and shrubs include beaked hazelnut (*Corylus cornuta*), chokecherry (*Prunus virginiana*), red-osier dogwood, and Saskatoon (*Amelanchier alnifolia*). Willows (*Salix* spp.) are one of the dominant shrubs found in association with wetlands in Saskatchewan. Shrub and tree encroachment into native grasslands is thought to be increasing with the decreased incidence of fire (Briggs et al. 2005, Van Auken 2009). Fire prior to European settlement would have helped to control such encroachment.

Wildlife that have the potential to occur within the study area include 51 species of mammals, 198 species of birds, 41 species of fish, 5 species of reptiles and 8 species of amphibians (Acton et al. 1998). Ungulates such as moose (*Alces americanus*), mule deer (*Odocoileus hemionus*), and white-tailed deer (*Odocoileus virginianus*) are common in the study area. Additionally, small populations of elk (*Cervus canadensis*) occur in the Allan Hills within the study area (Arsenault 2008). Pronghorn antelope (*Antilocapra americana*) can also be observed in the southern portion of the study area (Acton et al. 1998). Plains bison (*Bison bison*) previously inhabited the Moist Mixed Grassland Ecoregion (Acton et al. 1998), but were overexploited upon human settlement and the last of the wild herds were killed around 1880 (Mandelbaum 1979). Remnant plains bison herds are typically confined to protected areas such as national parks. Additional species of mammals that are common in the study area include beaver (*Castor canadensis*), coyote (*Canis latrans*), deer mouse (*Peromyscus maniculatus*), northern pocket gopher (*Thomomys talpoides*), muskrat (*Ondatra zibethicus*), porcupine (*Erethizon dorsatum*), raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*), Richardson's ground squirrel (*Urocitellus richardsonii*), striped skunk (*Mephitis mephitis*), and white-tailed jack rabbit (*Lepus townsendii*).

The Prairie Pothole Region (PPR) of North America includes five north-central states in the U.S. and three Canadian provinces, including the southern third of Saskatchewan (North American Bird Conservation Initiative 2016). The PPR provides a mosaic of small shallow wetlands of great conservation importance to migratory avian species, including waterfowl (Ando and Mallory 2012). The study area occurs in the PPR and the majority of the landscape has been converted from a landscape of native grassland and wetlands with or without trees and

shrubs, to a matrix of agricultural cropland, paved and unpaved roads, drained wetlands and cleared woody vegetation (AAFC 2013, AAFC 2014a). Remnant native vegetation occurs in fragmented patches as wetlands and riparian areas within agricultural cropland. Larger areas of native vegetation remain as grassland used for livestock production (Acton et al. 1998, AAFC 2013, AAFC 2014a).

The prairie landscape has been severely altered by anthropogenic activity, largely over the past 100 years (Acton et al. 1998). This alteration includes the cultivation of native grasslands, clearing of native trees, planting of non-native trees in linear shelterbelts within cropland, and the development of an extensive road and highway system. Humans continue to modify the landscape with agricultural cropping of monocultures, introduction of domestic livestock, expansion of utilities (power lines, pipelines), and urban and acreage development.

3.3. Methods

3.3.1. Capture and Collaring Study Animals

On February 18 and 19, and March 23, 2013, 19 adult female moose were captured and fitted with Global Positioning System (GPS; Global Positioning Solutions brand) collars. An additional 20 adult female moose were captured and fitted with GPS collars on March 13 and 14, 2014. The Global Positioning Solutions GPS collars weighed approximately 1.4 kg. These collars had GPS receivers within them that acquired a position hourly and transmitted these locations to a secure website via an Iridium satellite link. One of the female moose captured in 2014 was fitted with a Lotek Wireless Fish and Wildlife Monitoring brand GPS collar that also acquired a location fix every hour. On March 23, 2013, three female moose were recaptured to replace GPS collars. Although distribution across the entire study area was taken into consideration for moose capture locations, moose are mobile animals and could not be expected to remain in the vicinity of their capture locations.

The collars used in my study provided a large amount of data in almost real-time which resulted in very low costs per location transmitted. When a collared animal had not moved for approximately 24 hours and is likely deceased, the collar was designed to emit a mortality signal so immobile animals could be found. The Global Positioning Solutions Inc. GPS collars were designed to have an estimated battery lifetime of two years (Global Positioning Solutions Inc. 2013). The Global Positioning Solutions Inc. brand collars were designed with a rot-strip that

naturally degrades and releases the collar from the individual animal. The drop-off of the collar ideally occurs before the battery expires and therefore, no additional capture of the animal would be necessary to retrieve the collar.

Moose were captured using a net gun fired from a helicopter. During capture in 2013, two cow moose died during net gunning due to cervical fractures, while in 2014, no moose died as a result of capture. Moose were not darted or chemically immobilized due to the high risks associated with drug preparation, drowning in wetlands, and increased duration of capture and recovery, as well as the risk of darted moose crossing highways. Each captured moose was physically restrained by human handlers and leg hobbles for the safety of both the capture crew and the animal. Each moose was also blindfolded to reduce stress and visual stimuli. When hobbled and blindfolded, each captured moose was fitted with a GPS satellite collar, and blood, hair, faecal, and tissue samples were collected. Blood serum samples were analyzed to test for pregnancy using progesterone as described in Section 3.3.3. All aspects of the capture and handling were approved by University of Saskatchewan Animal Use Protocol No. 20130004, and the Saskatchewan Ministry of Environment Research Permits No. 13FW035 and 14FW054 (Saskatchewan Ministry of Environment 2013, Saskatchewan Ministry of Environment 2014).

3.3.2. GPS Collar Fix Success and Spatial Error Testing

Vegetation cover is usually one of the main obstacles for GPS satellite reception (Dettki et al. 2004). A subsample of the 2013 collars (n = 17) and 2014 collars (n = 10) were tested prior to deployment in different vegetative cover (e.g., coniferous forest, deciduous forest, wetland vegetation, open cropland) that would be encountered during the study. Due to the limited time frame between collar arrival and deployment in both years, the 2013 and 2014 collars were tested for 17 and 49 hours, respectively. Collars were left on the ground at known locations and the spatial deviance from this location was measured. Collars tested in 2013 and 2014 had an average spatial error of 15 m (SD = 13) and 21 m (SD = 15), respectively.

Additionally, GPS fix success (# successful fixes / # of attempted fixes) was quantified prior to collar deployment to ensure that the collars could transmit data locations equally in all habitat types. This capability reduced bias in habitat use classifications (e.g., overestimation of locations in open habitats). During testing of the 2013 collars, GPS fix success ranged from 88% to 100% with only two of the collars having less than 100% fix success. In 2014, the tested

collars had a GPS fix success ranging from 86% to 100% with only three of the collars having less than 100% fix success. One collar with 100% fix success recorded an extra location fix between the hourly fixes and stored duplicate locational fixes. One collar with 86% fix success took two extra location fixes between the hourly fixes. All locational fixes during testing, other than duplicates or unscheduled fixes between hourly fixes, were recorded using three or more satellites in view. Specifically, during the first 20 days post-parturition in both 2013 and 2014, GPS collars used in the analysis had 88.8% fix success.

3.3.3. Determining Pregnancy

Blood samples (serum) from each captured moose in March 2013 and 2014 were analyzed for progesterone levels to determine female pregnancy status. Prairie Diagnostic Services Inc. analyzed samples using a standard progesterone test. Prairie Diagnostic Services Inc. used threshold progesterone levels of ≥2.0 ng/ml to indicate pregnancy and ≤1.0 ng/ml as insufficient to support pregnancy. The pregnancy status of each female moose was confirmed during the subsequent summer calf surveys.

3.3.4. Moose Calf Surveys

Pedestrian surveys were conducted during two time periods in 2013 and 2014, and once in 2015. Pedestrian surveys were conducted to determine the number and survival of calves with each GPS-collared moose during the post-parturition period (June/July) and in the fall period prior to the Saskatchewan draw hunting season (September) in 2013 and 2014. Each collared adult female was located by a field team of three to five members that approached the last known GPS collar location of the moose. From this location the field team used triangulation of the VHF signal from the collar to further locate the female. The collared female moose and any associated calves were flushed from cover in order to achieve a more accurate count of calves with each collared female. The percentage of females with twins, a single calf, or no calves was determined from these surveys. Female moose with young calves are not social and typically avoid other moose (both males and females) during calving and post-calving through the summer season. The GPS-collared moose calved in mid to late May (see Section 3.4.2). However, calving surveys were conducted in June and July to allow for increased mobility of the young and prevent the separation or abandonment of neonate moose calves from their dam. The delayed

timing of these surveys also increased the safety of survey teams which included volunteers, as the mobile young were quick to flee from surveyors and therefore the surveys did not entice defensive or aggressive responses from adult females. Only female moose with visually confirmed calves were included in the analysis to determine the selection of parturition sites (n = 27) and, of those, only females that had adequate fix success during the 20-days post-parturition period (n = 14) were used in the RSF analysis.

Although ideally these surveys would have occurred as soon as possible after parturition to avoid a calf having been born and subsequently dying undetected, conducting surveys within the first 20 days post-parturition would have biased the habitat selection that was under investigation. There is also the risk of calf abandonment during these calf surveys that was largely mitigated by waiting until the calves were older and better able to follow their mother when flushed from cover. Surveys were conducted mainly in the morning and not during inclement weather to avoid negatively impacting the calf by flushing it out of cover and risking excessive heat or cold exposure.

3.3.5. Screening Moose Location Data

The main objective of data screening is to remove false locations such as large positional outliers based on unrealistic animal movement rates (Bjørneraas et al. 2010). The amount of location data removed was minimized while maintaining and improving the quality and accuracy of the data remaining. Screening procedures attempted to balance data accuracy with data loss (Bjørneraas et al. 2010). After the 2014 calving season, all May and June location data for post-parturient moose with young in 2013 or 2014 were downloaded from the secure project website, and the following screening procedures were performed. Locations that had latitude and/or longitude values of zero were removed from the dataset. Duplicate locations were screened by using the date and time stamp on each location, and these were removed from the dataset as well. Positional outliers were excluded rather than to attempt a spatial correction. Inaccurate fixes can often be removed by understanding the movement patterns and the maximum physical capability of movement distances between location fixes of the study animal. When the location data from a collared moose showed multiple days or consecutive hours with an extremely high and unrealistic movement rate, the positional outlier(s) was removed from the dataset.

3.3.6. Determining Timing and Location of Parturition Sites

The date and location of parturition was determined by first examining daily movement rates (km/day) of individual animals during the typical annual period for moose calving (i.e., May and June; Altmann 1958, Testa 2000a). Daily movement rates for each animal were calculated as the sum of all lengths for each day between individual one-hour GPS fixes and standardized by dividing by the number of GPS fixes successfully acquired that day. These movement rates were analysed for a sudden sharp drop in movement per day, which generally followed a larger peak in the daily movement rate (Testa et al. 2000a, Poole et al. 2007, McLaren et al. 2017). The sudden decrease in movement rate and localized clustering of GPS collar locations were characteristic of parturition (Brook 2010, McLaren et al. 2017).

For each female moose, GPS collar data after a large peak in movement rate in either May or June were examined in ArcGIS to see the extent of clustering of locations. The method of using movement rates and clustering of locations was used to determine the estimated parturition date and location. The date of parturition was assumed to be on the day with the shortest distance moved, which involved a clear decrease in daily movement in all cases. Daily movement rates were determined for the period from 5 days pre-parturition through the first 20-days post-parturition using GPS-collar locations. Pregnancy data and observed calf counts were also used in interpreting the movement data and clustering of GPS collar locations. For example, if the blood analysis indicated a female moose was not pregnant and the individual did not demonstrate a movement pattern characteristic of parturition, these two results along with absence of a calf during calf surveys, helped to verify that parturition did not occur.

For each female moose, movement rates and clustering in the GPS collar data were used to estimate a 24-hour period including parturition. The locations within the 24-hour parturition period were used to develop a 50% minimum convex polygon (MCP) using a floating median. Parturition site MCPs were developed in the Home Range Tools extension for ArcGIS (Rodgers et al. 2007). A 50% MCP was used to focus the parturition site to the core area being used during parturition (Harris et al. 1990). Kernel utilization distribution methods were not used to delineate the parturition site as these areas were very small and clustered without enough relocation points to warrant the development of a kernel. The floating median method calculates the median of all points, removes a single point that is farthest from the median, recalculates and removes the next point farthest from the new median until the desired percentage of relocation points remains. The

floating median MCP method was used as it is more robust against outlier locations compared to the floating mean MCP method.

A centroid point of each animal's estimated parturition site MCP was buffered by 100 m. This buffer size was chosen because 100 m was the mean hourly movement of collared female moose. A buffer around each individual moose location allows the proportion of habitat to be quantified at each used point. As well, considering used locations as an area rather than as a telemetry point has a theoretical basis in overcoming bias, such as spatial error, in habitat selection studies (Rettie and McLoughlin 1999). Additionally, the animal likely acquired knowledge of the habitat at least 100 m around their chosen parturition site and possessed sensory surveillance of the habitat within 100 m of the site during parturition.

3.3.7. Habitat Selection during Parturition

Delineating parturition sites for individual animals allows for the investigation of habitat selection at different spatial and temporal scales. Habitat selection was analyzed at two scales; at the parturition site and within each animal's home range during the first 20 days post-parturition. For the parturition site analysis using habitat selection ratios, the study area was re-defined as a 100% minimum convex polygon (MCP) of used locations during the calving season. May and June 2013 and 2014 locations of parturient females (n = 19) were used to develop this MCP (n = 22,068 used locations). The re-defined study area was smaller and more biologically representative of available parturition site habitat.

In addition to the Wildlife Management Zones (WMZs) in the original larger study area, a small portion of the Regina Wildlife Management Zone and WMZ 30 were included in the re-defined study area based on actual movement data from the collared moose. A small area of WMZ 30 is included at the northern extent of the study area (southern extent of the WMZ 30) and a small area of the Regina WMZ is included at the southeastern extent of the study area (northwestern extent of the Regina WMZ).

3.3.7.1. Land Cover Covariates

Habitat types used by or available to moose were quantified using the AAFC annual land cover map (Table 3.3; AAFC 2013, 2014a). The land cover map is based on 30 m spatial resolution Landsat imagery from 2013 and 2014 (AAFC 2013, 2014a). Each year's land cover

map was associated with the appropriate year for the moose location data. These datasets were ground-truthed and found to be between 82% to 87% accurate depending on the year (AAFC 2014b). Wetlands and riparian areas, including trees and shrubs, within the home ranges of the individual moose were hand digitized using satellite imagery to ensure accurate classification of this perceivably important habitat type. Road density was initially considered as a covariate. However, the network of roads in the study area is relatively uniform and therefore it was anticipated that moose habitat selection would be influenced by roads at a smaller scale.

Table 3.3 Hectares (ha) and percentage of land cover (habitat) covariates in the study area from the Agriculture and Agri-food Canada 2014 census

Land Cover Type	Description	ha	%
Cereals	Crops for grain production including spring and winter wheat, barley, oats, rye, triticale, millet, spelt, canary seed, corn and other grains.	148,487	26.8
Oilseeds	Crops for oil production including canola, flax, soybeans, mustard, camelina, safflower, borage, sunflowers.	134,755	24.3
Pulses	Crops including peas, lentils, and beans.	92,656	16.7
Pasture & Forages	Includes tame grasses and other perennial forages such as alfalfa, grown alone or in mixed stands for hay, pasture, or seed production. Land can be periodically cultivated.	64,167	11.6
Native Grassland	Primarily native grassland and can include some shrub cover.	24,285	4.4
Wetland & Riparian areas	Land with a water table at, near, or above the soil surface for a long enough period to develop vegetation and soils characteristic of hydric conditions. Riparian areas include trees and shrubs associated with wetlands.	48,959	8.9[(a)]
Developed	Includes urban and developed areas, and road surfaces.	12,201	2.2
Trees and Shrubs	Woody vegetation including shrubs ~2 m or greater in height, and coniferous, deciduous and mixed forests.	11,209	2.0
Minority Crops & Unseeded Cropland	Including fruit, vegetables, and hemp, exposed land, and fallow or unseeded cropland due to excess moisture in the spring.	17,243	3.1
Total		**553,963**	**100.0**

[(a)] Wetlands and riparian areas within the home ranges of the individual moose were hand digitized using satellite imagery to ensure accurate classification of this perceivably important habitat type. Riparian areas included trees and shrubs.

3.3.7.2. Selection Ratios

Selection ratios (SRs) were used to quantify the resource selection of female moose at the time of parturition. Selection ratios were calculated using land cover (habitat) covariates selected for investigation *a priori*. The proportion of the covariates used to the proportion available within the study area was used to calculate SRs. The SR equation is:

$$w_i = O_i / \pi_i \tag{3.1}$$

where O_i refers to the proportion of a land use covariate used by a female moose during the calving season, and π_i is the proportion of that same covariate that is available as determined by randomly generated locations throughout the study area (Manly et al. 2002). The selection threshold is 1. If use of a habitat type is greater than its availability, selection is occurring and SR > 1. If the habitat type is being avoided (i.e., used proportionately less than available), then SR < 1. If the habitat type is being used in proportion to its availability it is neither selected nor avoided and SR = 1.

Chi^2 goodness-of-fit tests were completed to compare observed and expected use of habitat types. The equation for the Chi^2 goodness-of-fit test is:

$$X_p^2 = \sum_{i=1}^{c} \frac{(O_i - E_i)^2}{E_i} \tag{3.2}$$

where O_i refers to the observed proportion of a land use covariate used by a female moose during the calving season, and E_i is the proportion of expected value of O_i. The summation is over all habitat categories (Neu et al. 1974, Byers et al. 1984).

Then the Bonferroni Z-statistic was used to construct 95% Bonferroni confidence intervals around the SRs (Byers et al. 1984). The equation used to calculate the Bonferroni confidence interval is:

$$p \pm Z_{a/2k}\sqrt{p(1\text{-}p)/n} \tag{3.3}$$

where *p* refers to the proportion of a land use covariate used by a female moose during the calving season, *n* is the total number of observations, and *k* is the number of habitat categories (Byers et al. 1984).

When the 95% Bonferroni confidence intervals for a selection ratio do not overlap with the selection ratio value of 1 (signifying use in proportion to availability), the selection ratios are considered significant (Byers et al. 1984). In order to quantify resource selection during parturition, available but unused parturition sites were randomly selected throughout the study area. Used to available sites were selected at a ratio of 1:10. These available points were buffered by 100 m to achieve the same area as the used parturition sites. The software Geospatial Modelling Environment (Beyer 2012) was used to generate the available points within the study area and to calculate the proportion of each habitat type within the buffered used and available parturition sites. I excluded these random, available locations from overlapping with the used locations. This was completed to prevent contamination or inclusion of sites used by moose in the unused sample of sites (Johnson et al. 2006). Using this MCP, areas where location data from post-parturient moose during the first 20 days post-parturition were not available were excluded (Johnson 1980, Boyce 2006).

A SR was calculated for all known moose parturition sites in 2013, 2014 and 2015. An additional SR was calculated for parturition sites used in 2014 only, in which specific crop types (e.g., oilseeds, pulses, cereals, minority crops and unseeded cropland) were separated to examine selection patterns in greater detail. Annual crops are often rotated and grown in different fields every year. This additional SR could only be calculated for 2014, due to the larger sample size of used parturition sites for that year. Selection ratios were also calculated using the nearest distance from used parturition sites to paved and unpaved roads.

3.3.8. Habitat Selection during the First 20 Days Post-Parturition

I hypothesized that wetlands and their associated riparian areas, and trees and shrubs not associated with wetlands would be important to female moose with vulnerable young. I hypothesized that native grassland, pasture, and hay land would also be important due to the lower amount of anthropogenic activity (i.e., disturbance) and potentially higher nutritional value compared to annual cropland. Moose are primarily a browsing species, so selection may depend on the degree in which post-parturient female moose in the prairies are consuming non-browse

vegetation at this time of the year. The early availability of forage on native grassland and in pasture and hay land compared to cropland, which would be newly seeded or only beginning to grow during this time, might act as an attractant for female moose with young.

To increase the relevancy of the study area for habitat selection of female moose during the first 20 days post-parturition, I developed a 100% minimum convex polygon (MCP) surrounding 6,410 used locations of 15 female moose confirmed to have calves. These used locations were specifically taken during the first 20 days post-parturition in 2013 and 2014. I buffered this MCP by 1 km to prevent removing habitat that was available to females during this time.

I compared used versus apparently non-used locations. I used Geospatial Modelling Environment software (Beyer 2012) to generate random available points within each of these home ranges equal to the number of GPS-collared moose locations (i.e., 1:1 ratio of used to available points). I generated 12,082 random locations across the MCP area. I buffered used and available points by 100 m, the mean distance travelled between hourly locations, in order to better characterize habitat use by this large and mobile mammal. Habitat variables were quantified as the proportion of each habitat type within the 100 m buffer around each used and available location. Using proportions of habitat types within buffers rather than point values enables modelling nonlinear selection (Hebblewhite and Merrill 2008, Chetkiewicz and Boyce 2009).

I built models of habitat selection by female moose with young aged 1 to 20 days old by comparing used and available habitats to develop a Resource Selection Function (RSF; Manly et al. 2002). I used a study design with 3rd order selection (i.e., used and available locations within individual home ranges) (Johnson 1980). I chose to limit the analysis to the neonate period when calf mobility is at its lowest and calf vulnerability is at its highest. This situation makes the habitat selected by parturient female moose critically important. Moose calf locomotion improves during the first 20 days post-parturition, and calves display heeling or imprinting and stay close to their dams (Altmann 1958). Furthermore, selecting a short period of time limits the time in which the habitat or resources available (e.g., seasonally) or requirements for a specific life stage can change (Manly et al. 2002).

3.3.8.1. Model Development

Because the habitat selection of moose in an agriculture-dominated landscape has only recently been characterized in the literature (Laforge et al. 2016) and the ecology of moose in this landscape is largely unknown, I was unable to specify a meaningful set of a priori models. Therefore, I chose to follow an exploratory approach to building and parameterizing models (Hochachka et al. 2007). I included the parameter of wetlands and riparian areas based on a priori knowledge that these areas, and the associated trees and shrubs, are important to moose in boreal forest ecosystems. A similar approach was also used by Laforge et al. (2016). Selection ratios were used to analyze resource selection during parturition. Land use covariates that were used in this analysis were also considered in model development for resource selection during the first 20 days post-parturition.

I used an information-theoretic approach suitable for complex ecological studies that examines multiple working hypotheses (Chamberlin 1965). My candidate RSF models were fitted using binomial generalized linear regression (Boyce et al. 2002). I used standardized variables (i.e., the mean subtracted and divided by SD) to allow for comparability of effect sizes. Standardized variables also facilitated model convergence (Schielzeth 2010). I used Akaike's Information Criterion (AIC; Burnham and Anderson 2002) to determine which model with its combination of habitat covariates would best predict the presence of female moose with young during the first 20 days post-parturition.

I examined fine scale habitat selection of female moose with young during the first 20 days post-parturition (n = 14; 11,938 locations). For each individual moose, I generated a 95% kernel utilization distribution using the animal's locations during the first 20 days post-parturition. I used the *ad hoc* method to estimate the smoothing parameter in the R statistical software (R Development Core Team 2014) package *adehabitat* (Calenge 2006). Using kernel methods to estimate home ranges have been recommended by many authors including Worton (1987, 1989, 1995) and is considered one of the most widely used home-range estimation methods in ecology (Hemson et al. 2005). The kernel method used in the *adehabitat* package (Calenge 2006) corresponds to that described by Worton (1995).

The land use covariates from the AAFC annual land cover inventory were examined for use as potential model parameters. The land cover type of Minority Crops & Unseeded Cropland represented undifferentiated agriculture land. Minority Crops & Unseeded Cropland was

removed as a potential model parameter as the selection or avoidance of this land cover type would have been difficult to interpret and likely not ecologically important. Consideration was given to merging the land cover types of native grassland, and pasture and forages into one habitat type as these habitats are both structurally grasslands. However, native grassland has a different plant species composition and often has different patterns of use by humans or livestock compared to tame pasture and forages. Both tame or seeded pasture and forages used for hay production typically contain one to four non-native species. Tame or seeded pasture can be more productive and grazed by livestock earlier in the spring than native grassland, while forages used for hay production are cut and baled in mid-summer. However, forages used for hay production can also be grazed by livestock. Due to the plant species distinctions between native grassland and tame pasture and forages, these two land cover types were examined separately during model development and selection.

'Distance to' covariates were calculated as the shortest distance between the moose location and the nearest covariate feature measured in kilometres. 'Distance to' covariates that were examined initially were distance to the nearest paved road, unpaved road, and town. When an environmental covariate was not present in each of the home ranges for individual moose, the covariate could not be considered available habitat for all individuals and was removed. The environmental covariate of 'Distance to Town' was removed from modelling since several home ranges of individual moose did not contain towns, villages, or hamlets. Paved roads and Unpaved roads were merged into a Roads parameter, as several home ranges of individual moose did not contain paved roads.

I used generalized linear mixed models (GLMMs) in the R package *lme4* with the glmer function (Bates et al. 2015), with Laplace approximation of the maximum likelihood. Generalized linear mixed models provide a more flexible approach for analyzing non-normal data, such as proportions of habitat, especially when random effects are present (Bolker et al. 2009). Moose ID was included in the model as a random factor (random intercept) to account for repeated measurements of the same individual (van Beest et al. 2013). Using Moose ID as a random effect accounted for individual variation and reduced bias in estimating habitat selection (Gillies et al. 2006).

A Spearman's Correlation Coefficient Matrix was used to identify and remove land use covariates that were highly correlated. Parameters that were strongly correlated (≥|0.7|) were removed (Dormann et al. 2013).

3.3.8.2. Model Selection and RSF Development

I selected the best-approximating model, that with the lowest AIC score, to develop a resource selection function (Manly et al. 2002). The RSF equation to calculate the relative probability of use for each resource (e.g., a map pixel) is:

$$w(x) = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 ... \beta_n x_n) \quad (3.4)$$

This RSF identifies habitat types important to female moose during the calving season, specifically during the first 20 days post-parturition. This RSF predicts the probability of use by female moose with calves during this period. Relative probability of selection links to habitat quality, where higher relative selection equates to higher quality habitat. Initially, I developed a global model that included all habitat types as well as the quadratic (squared) term for each variable to incorporate nonlinearity (Guisan et al. 2002). Based on previous research, I had no a priori reason to expect nonlinear responses more complex than those that could be represented with a quadratic term (Laforge et al. 2016). Interactions terms that made biological sense were also included in the model selection process to determine if these interactions improved model fit (by reducing the AIC score). I used backwards selection to find the optimal model with the best fit by dropping variables and interactions that increased the AIC score.

ArcGIS (Environmental Systems Research Institute, Redlands, CA, USA) was used to generate a map displaying the relative probability of selection or resource selection function (RSF) based on the top model. This map predicts the relative probability of selection for female moose with young during the first 20 days post-parturition within the 95% kernel home ranges of individual moose. In order to evaluate the spatial predictive ability of the top model, I used Spearman's correlations through *k*-fold cross-validation with k=5 folds, based on a hold-back dataset of female moose GPS-collar locations. This cross-validation was completed following Boyce et al. (2002).

3.4. Results

3.4.1. Pregnancy Rates

The pregnancy rate of GPS-collared female moose was 84% in both 2013 (n = 16/19) and 2014 (n = 16/19). Non-pregnant animals had blood progesterone levels ≤1.0 ng/ml, while pregnant animals had blood progesterone levels ≥2.0 ng/ml. None of the blood samples from GPS-collared moose had progesterone levels between the 1.0 and 2.0 ng/ml thresholds. This provided additional confidence in the pregnancy status assignment. Furthermore, moose calves were not observed with females that were classified as 'not pregnant' through this method.

3.4.2. Timing and Location of Parturition Sites

I located 27 parturition sites between 2013 and 2015 (Figure 3.2 and 3.3). The mean parturition date for all years combined for the 27 female moose was May 21 with a range from May 13 to May 29. All 27 females were determined to be pregnant using progesterone analysis from blood samples. Examining individual parturition sites using satellite imagery showed that moose calved near wetlands and within riparian habitat (Figure 3.4). The locations of parturition sites were determined by examining GPS collar data and daily movement rates for localized movement during May and June. At no other time during May and June of each year, were such localized movement patterns observed in the GPS data. A typical daily movement rate (km/day) pattern of a female parturient moose is shown in Figure 3.5, while the mean daily movement rate of all female parturient moose is shown in Figure 3.6. The mean peak in daily movement rate on the day before parturition was 4.7 km/day (SD = 4.0) with a range of 19.7 to 1.3 km/day. From 5 to 2 days prior to parturition, the mean daily movement rate was 2.8 km/day (SD = 0.6). The mean daily movement rate on the estimated day of parturition was 0.6 km/day (SD = 0.4). The mean daily movement rate of pregnant females that had calves present during the June calf surveys (i.e., with surviving calves) was 0.8 km/day (SD = 0.8) on the day after parturition and remained <1.0 km/day for the first four days after parturition. The mean daily movement rate of these females was <2.0 km during the 20-day post-parturition period, except for one day when one female travelled 15.1 km. This outlier resulted in a mean daily movement rate of 2.5 km/day (SD = 3.2) on Day 14 post-parturition. The mean daily movement rate of females with surviving

calves was 1.4 km/day (SD = 1.2) from day 3 to day 20 post-parturition. Movement rates of female moose with calves increased over the first 20 days post-parturition.

Daily movement rates of two pregnant GPS-collared female moose that did not have calves with them during calf surveys are shown in Figure 3.7. After parturition, the daily movement rates of these female moose were larger compared to the daily movement rates of females with calves. The mean daily movement rate of these two females was 2.6 km/day (SD = 2.0) on the day after parturition, and 3.0 km/day (SD = 1.9) from day 3 to day 20 post-parturition.

Moose calf locomotion improves during the first 20 days post-parturition, and calves display heeling or imprinting and stay close to their dams (Altmann 1958). After 26 days post-parturition, movement rates of female moose approach pre-parturition levels (Testa et al. 2000a). In my study, the movement rates of female moose with calves increased over the first 20 days post-parturition. However, there was individual variation in when movement rates approached pre-parturition levels. Movement rates did not reach pre-parturition levels until late June/early July for the majority of female moose with young, which was typically over 35 days post-parturition. M034 and M060 were two females with young whose movement rates increased quickly and approached pre-parturition levels in early June. M060 had two calves, while M034 had one calf. M031 and M033 were two females with young whose movement rates did not approach pre-parturition levels even by the end of July. Both of these females had one calf. Parturition dates did not appear to explain the individual variation in movement rates.

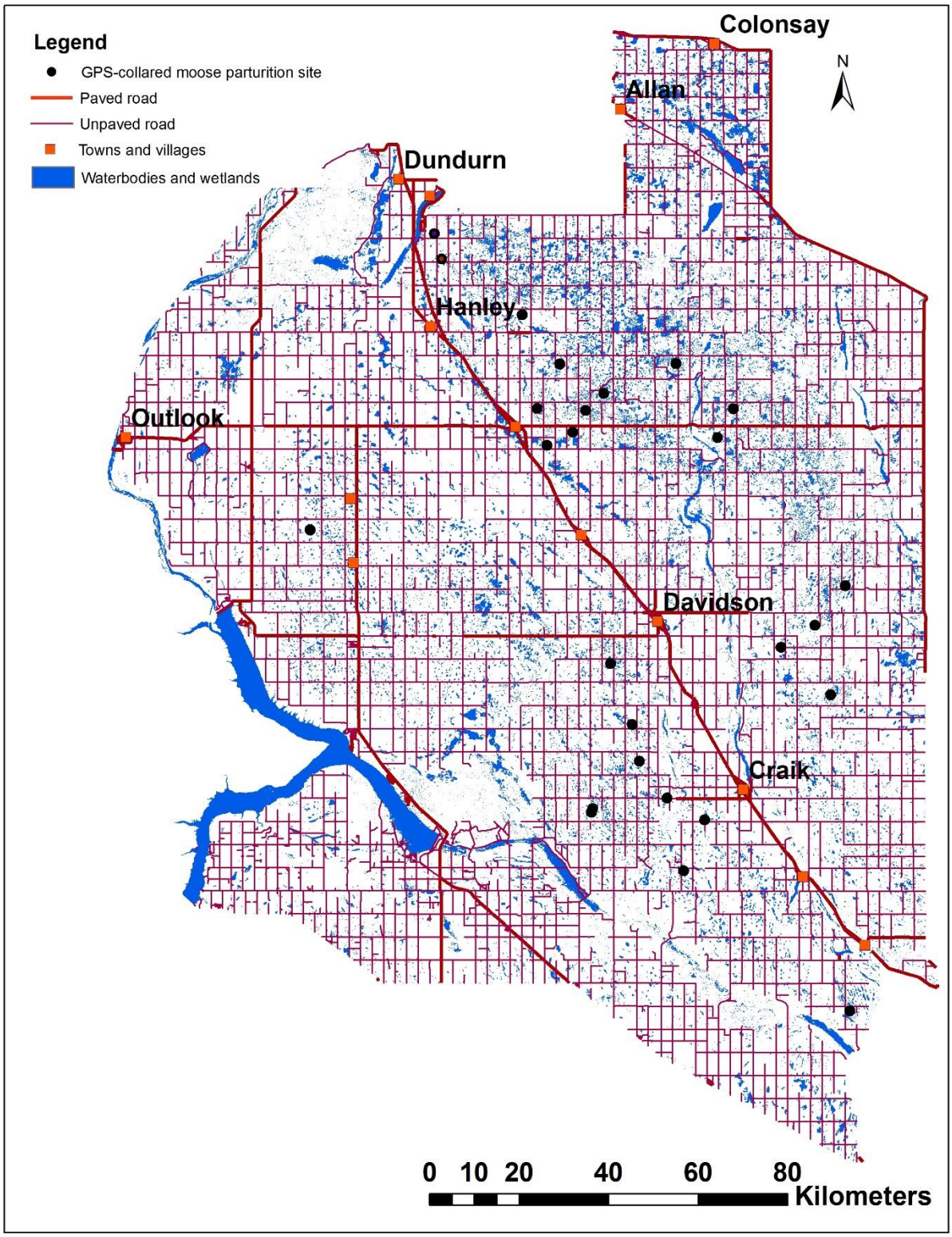

Figure 3.2. Locations of 27 parturition sites of GPS-collared adult female moose between 2013 and 2015 within the original study area. There are two areas where two parturition sites overlap in this map. Parturition sites are not displayed to scale; enlarged for visualization.

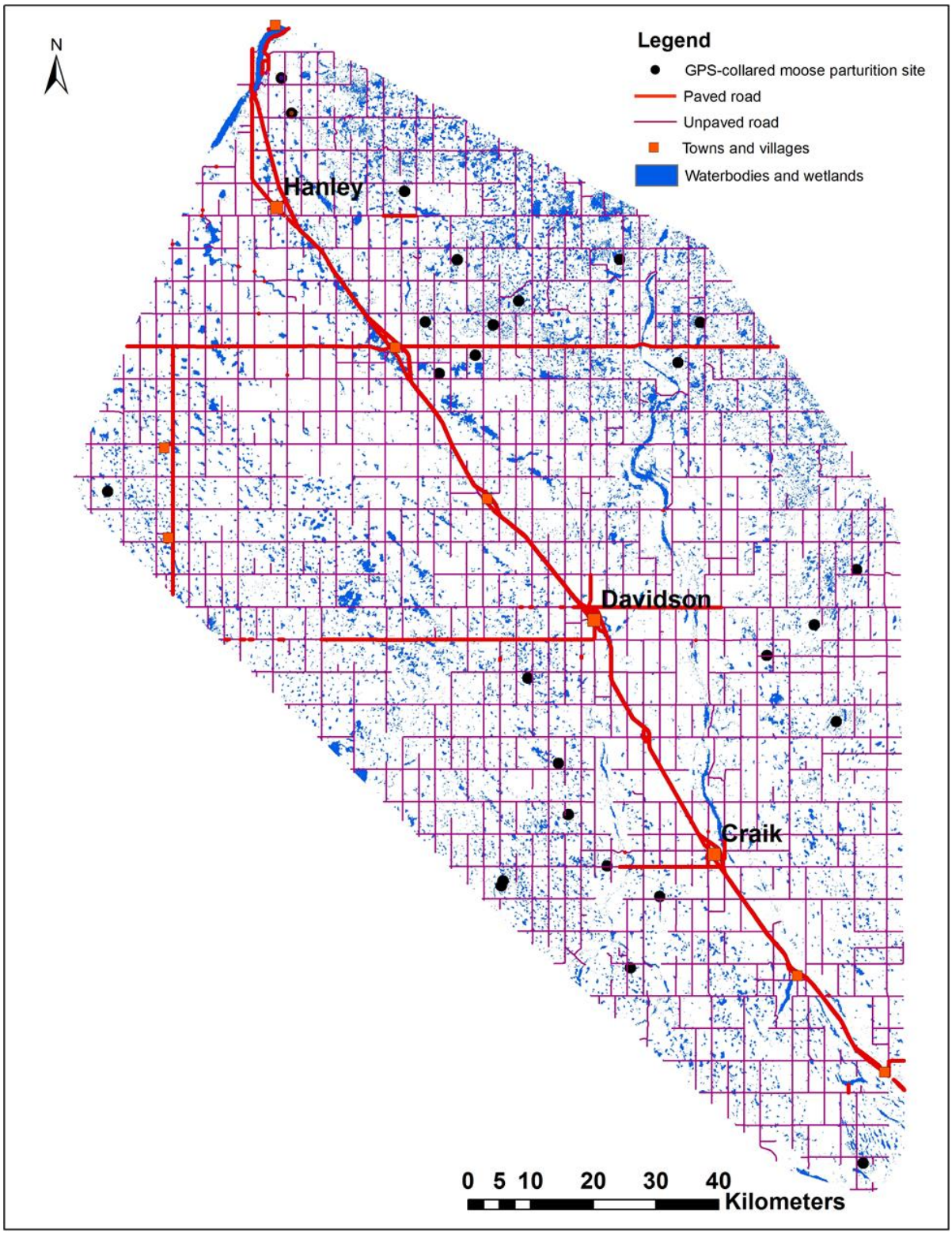

Figure 3.3 Locations of 27 GPS-collared moose parturition sites between 2013 and 2015 within the re-defined and smaller study area. There are two areas where two parturition sites overlap in this map. Parturition sites are not displayed to scale; enlarged for visualization.

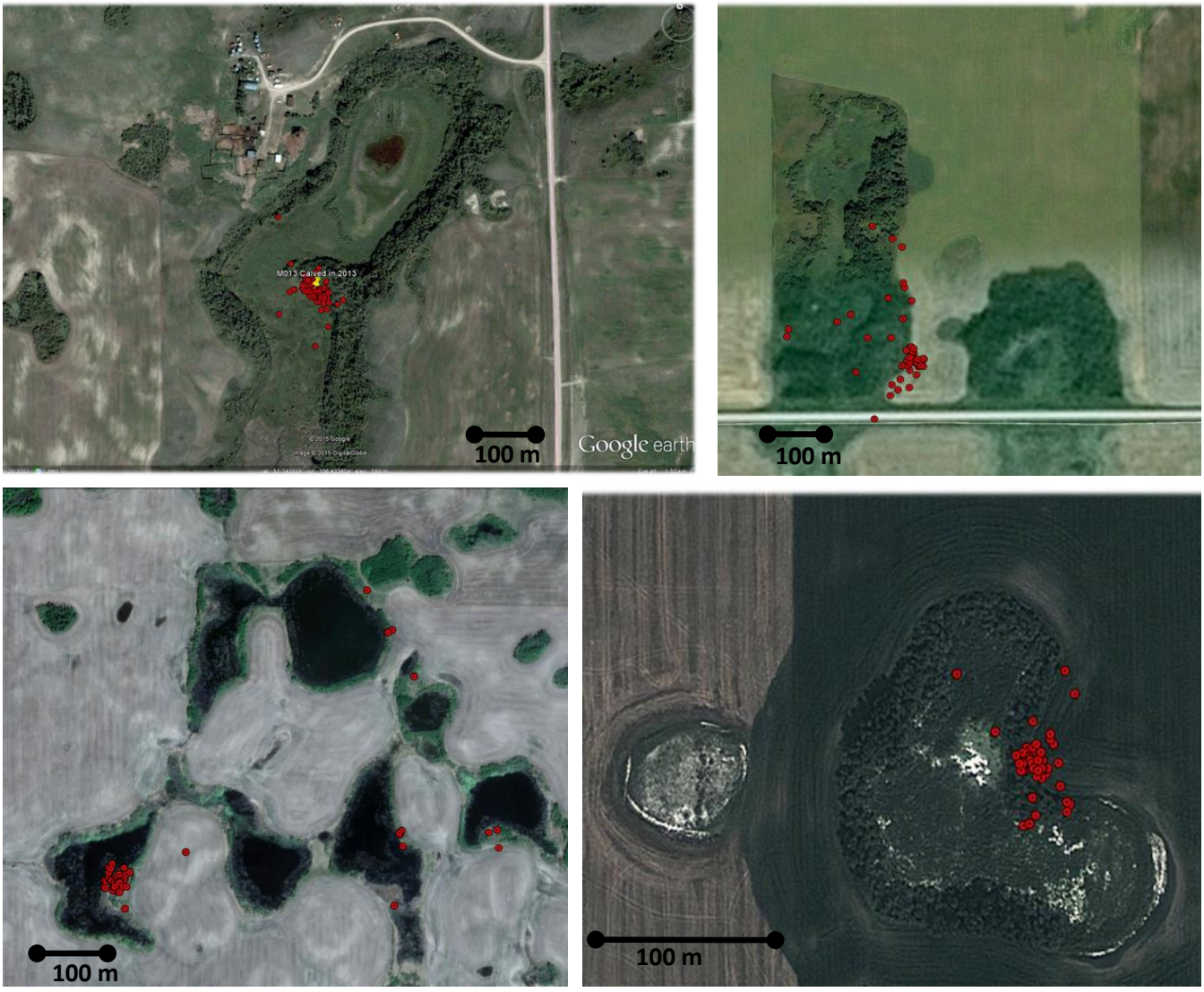

Figure 3.4 Aerial imagery showing hourly telemetry locations of four individual female moose during parturition.

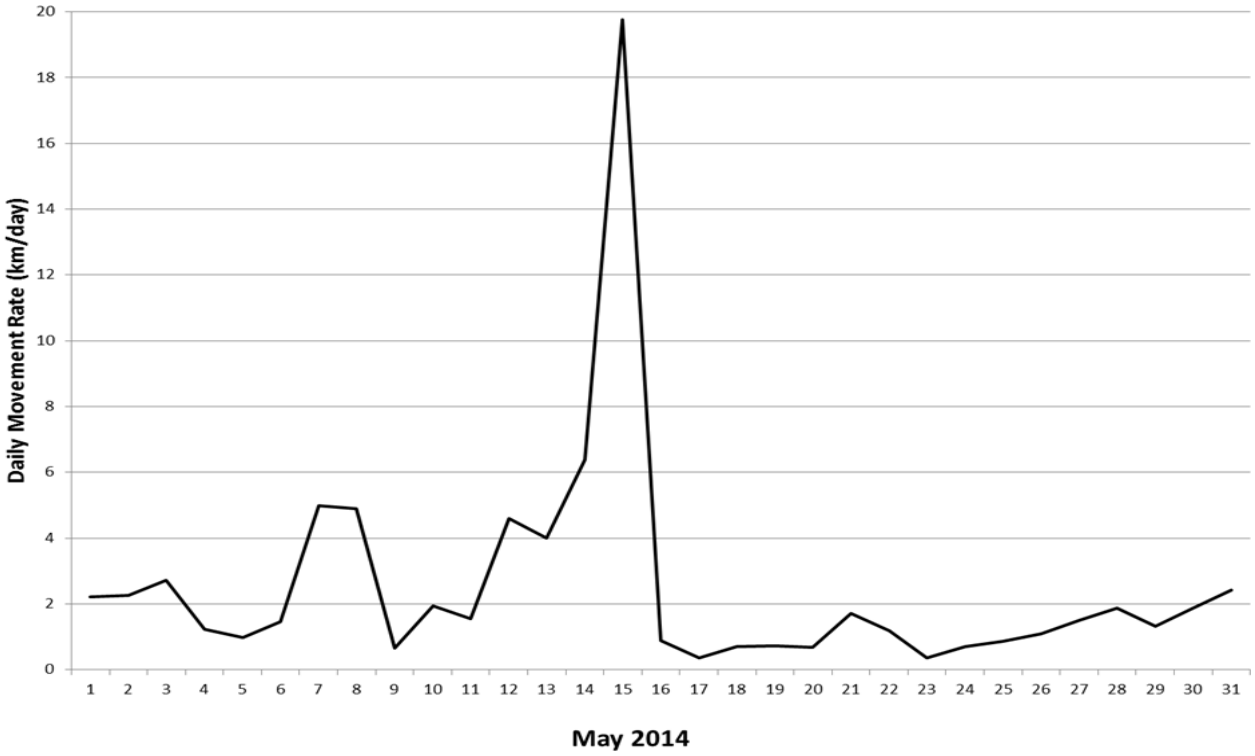

Figure 3.5 Daily movement rate (km/day) of a pregnant GPS-collared female moose in May 2014 used to estimate the date of parturition. This female moose calved on May 16 of that year. This movement pattern with a peak before parturition and a low movement rate on the day of parturition represents the typical movement pattern observed by parturient GPS-collared female moose in the study.

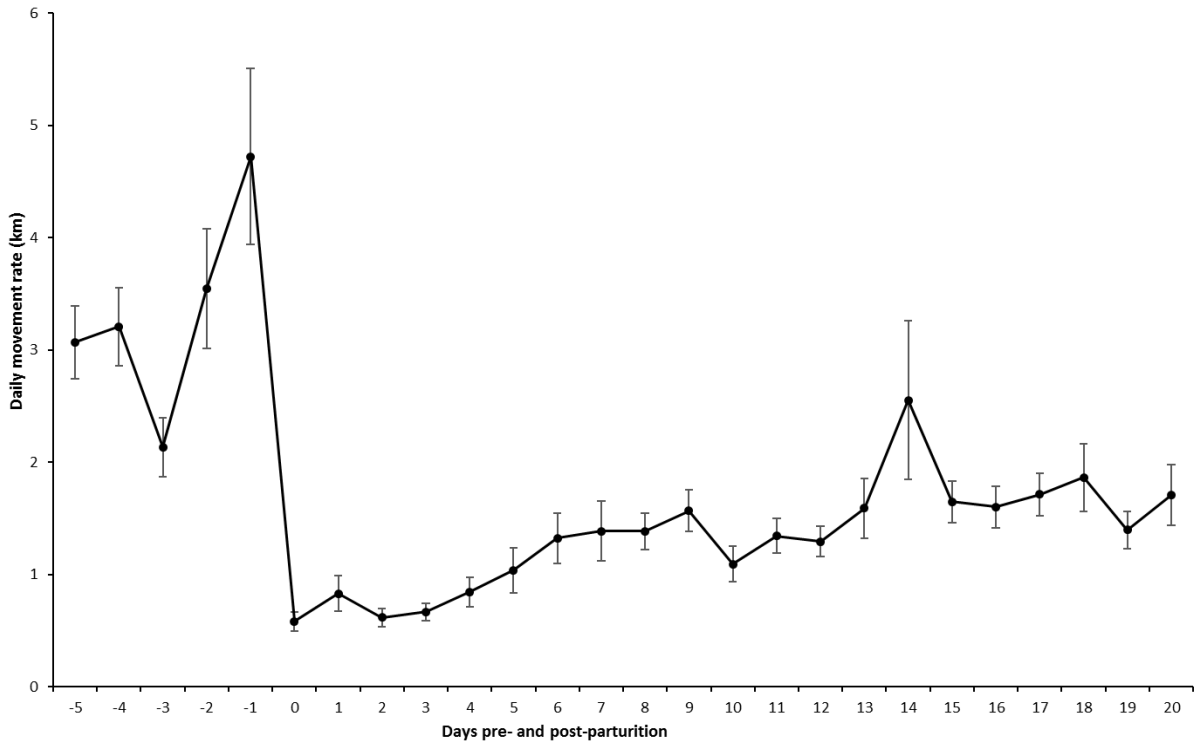

Figure 3.6 The mean daily movement rate (km/day) of all parturient GPS-collared female moose that calved in 2013 and 2014 from 5 days prior to parturition to 20 days post-parturition. Day 0 represents the date of parturition for each individual moose regardless of the calendar date.

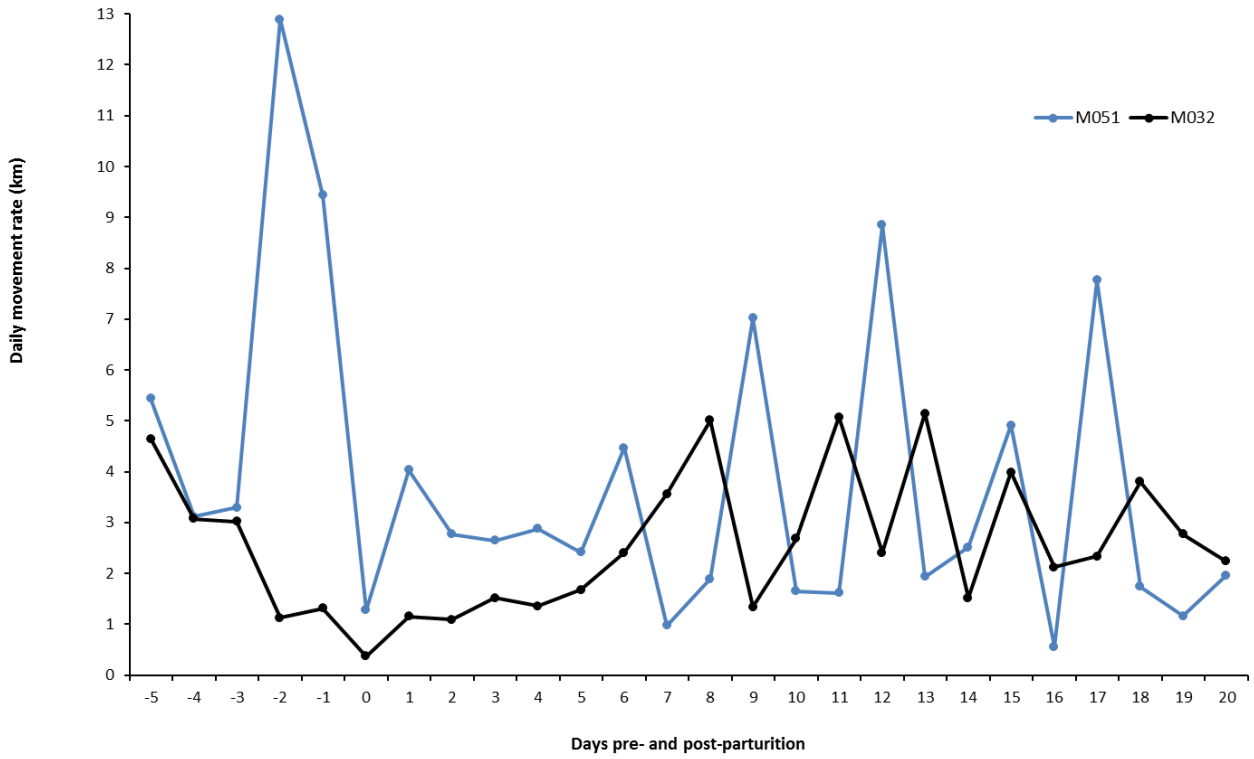

Figure 3.7 Daily movement rates (km/day) from 5 days prior to parturition to 20 days post-parturition of two pregnant GPS-collared female moose that did not have calves during calf surveys. Day 0 represents the date of parturition for each individual moose regardless of the calendar date.

3.4.3. Moose Calf Surveys

Of pregnant females observed with one or two calves, twinning rates were 66.7% in June 2013 (n = 6/9) and 45.5% in June 2014 (n = 5/11). Five pregnant female moose were subsequently observed without calves during the June calf surveys (n = 3 in 2013, n = 2 in 2014). I was unable to determine if these pregnant females had given birth to twins or a single calf, and as such, these females cannot be included in the twinning rate calculations. Only two females (M013, M016) were observed with calves during two consecutive years. In 2013, M013 had twins and in 2014 was observed with a single calf. In 2013, M016 was observed with a single calf and in 2014 had twins. M051 reproduced during two consecutive years (2014 and 2015), but lost her young prior to the summer field survey in 2014.

Females with calves that could not be relocated in both June and September were not included in the calf survey results in Figure 3.8. Three females in 2013 and two in 2014 were excluded. The results of each moose calf survey could only include females that were observed in both June and September of the same year to prevent misinterpretation of calf survival during this period of time (Figure 3.8). In 2013, two females that had single calves successfully raised their calves until September of that year. In 2013, two of four females with twins in June had lost one or both calves by September. In 2014, 6 females that had single calves successfully raised their calves until September. In 2014, 3 of 4 females with twins in June had successfully raised their twin calves until September. The other female had lost one calf during that period.

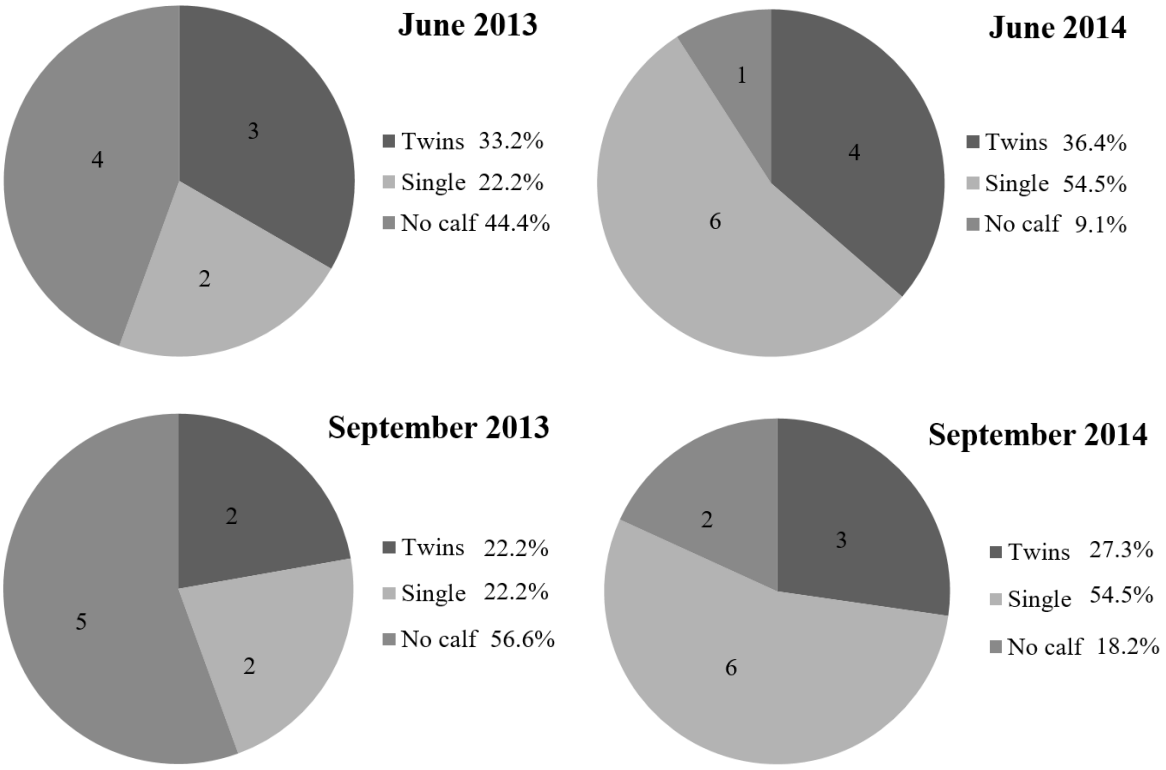

Figure 3.8 Percentage of pregnant female moose surveyed that had twins, one calf, or no calves in June and September of 2013 and 2014.

3.4.4. Habitat Selection during Parturition

Wetland and riparian habitat, with trees and/or tall shrubs, was present within each of the 27 parturition sites. Trees and shrubs surrounding wetlands were included in the wetland and riparian habitat type. The size of the wetland at the parturition site varied per individual moose; however, the mean wetland size was 3.45 ha with a standard deviation of 4.10 (Table 3.4). The mean number of wetlands within the 100 m buffered parturition site was 1.93 (SD = 1.25). Other habitat types were often located within the 100 m buffer of the parturition site including cropland, tame pasture and forages, and native grassland. Of the 27 parturition sites, 77.8% (n = 21) included cropland, 14.8% (n = 4) included tame pasture and forages, and 11.1% (n = 3) included native grassland within the 100 m buffer (Table 3.4). Because these parturition sites can have multiple habitat types (e.g., cropland and native grassland) the percentage of habitat types summed together is slightly greater than 100%. The proportion of habitat type observed at each

parturition site is provided in Table 3.5. The habitat type with the largest mean proportion was wetland and riparian habitat (0.48 [SD = 0.24]), followed by cereal crops (0.14 [SD = 0.18]). The habitat type with the smallest mean proportion was native grassland (0.00 [SD = 0.01]), closely followed by developed (0.01 [SD = 0.03]) and minority crops and unseeded cropland (0.01 [SD = 0.07]).

The mean distance to the nearest paved road from each parturition sites was calculated. The mean distance from a paved road to a parturition site was 5.70 km (SD = 4.19). There was substantial individual variation in distance to the nearest paved road from parturition sites, with a range of 0.77 to 16.08 km (Table 3.6). The mean distance from an unpaved road to a parturition site was 0.57 km (SD = 0.39).

Table 3.4 Size and number of wetlands and habitat located within the 100 m buffer of the parturition sites.

No.	Year	Moose ID	Calving Date	Parturition Wetland Size (ha)	No. of Wetlands in 100 m Buffer	Other Habitat Types within 100 m Buffer
1	2013	M005	May 19	7.34	3	Native grassland, Trees and Shrubs
2	2013	M008	May 26	1.20	1	Cropland
3	2013	M013	May 27	16.06	1	Valley with a creek
4	2013	M017	May 24	17.18	1	Cropland
5	2014	M011	May 16	5.57	2	Cropland
6	2014	M013	May 26	3.90	1	Cropland
7	2014	M016	May 18	1.70	1	Cropland
8	2014	M026	May 13	0.28	6	Cropland
9	2014	M029	May 26	1.41	1	Cropland
10	2014	M031	May 22	1.32	1	Cropland
11	2014	M032	May 24	5.37	2	Cropland, Road
12	2014	M033	May 26	3.58	1	Cropland
13	2014	M034	May 21	1.41	1	Cropland
14	2014	M037	May 18	0.68	4	Cropland
15	2014	M044	May 23	1.49	3	Pasture/Forages
16	2014	M051	May 29	3.48	2	Pasture/Forages
17	2014	M060	May 17	0.64	3	Native grassland, Cropland
18	2014	M061	May 19	0.37	4	Pasture/Forages
19	2014	M062	May 18	2.32	1	Cropland
20	2015	M011	May 19	3.83	1	Cropland
21	2015	M026	May 19	0.66	1	Cropland, Native grassland
22	2015	M033	May 20	2.23	1	Cropland
23	2015	M037	May 17	0.65	3	Cropland
24	2015	M044	May 17	2.99	2	Cropland
25	2015	M051	May 25	2.74	1	Pasture/Forages
26	2015	M060	May 14	1.55	2	Cropland, Road
27	2015	M063	May 21	3.19	2	Cropland
Mean			**May 21**	**3.45**	**1.93**	**-**
Standard Deviation			**4.25**	**4.10**	**1.25**	**-**

Table 3.5 Proportion of habitat variables within the 100 m buffers of the 27 GPS-collared moose parturition sites.

No.	Year	Moose	Proportion of Habitat Variable								
			Wetland & Riparian	Developed	Native Grass-land	Minority Crops & Unseeded	Pasture & Forages	Cereals	Oilseeds	Pulses	Trees & Shrubs
1	2013	M005	0.23	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.13
2	2013	M008	0.44	0.00	0.00	0.00	0.00	0.28	0.28	0.00	0.00
3	2013	M017	0.43	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00
4	2013	M013	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	2014	M011	0.56	0.00	0.00	0.40	0.00	0.03	0.01	0.00	0.01
6	2014	M013	0.60	0.00	0.00	0.00	0.00	0.30	0.10	0.00	0.00
7	2014	M016	0.60	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00
8	2014	M026	0.51	0.00	0.00	0.00	0.00	0.15	0.03	0.00	0.31
9	2014	M029	0.18	0.00	0.00	0.00	0.00	0.00	0.82	0.00	0.00
10	2014	M031	0.23	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00
11	2014	M032	0.58	0.12	0.03	0.00	0.00	0.28	0.00	0.00	0.00
12	2014	M034	0.46	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.07
13	2014	M033	0.98	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
14	2014	M037	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00
15	2014	M044	0.43	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.21
16	2014	M051	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.07
17	2014	M060	0.89	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00
18	2014	M061	0.25	0.00	0.00	0.00	0.50	0.20	0.00	0.00	0.05
19	2014	M062	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00
20	2015	M060	0.75	0.11	0.00	0.00	0.00	0.09	0.00	0.06	0.00
21	2015	M044	0.52	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00
22	2015	M037	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.00
23	2015	M063	0.41	0.00	0.00	0.00	0.00	0.00	0.53	0.00	0.06
24	2015	M026	0.16	0.00	0.03	0.00	0.04	0.32	0.00	0.08	0.37
25	2015	M033	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00
26	2015	M011	0.17	0.00	0.00	0.00	0.44	0.37	0.00	0.00	0.02
27	2015	M051	0.25	0.00	0.00	0.00	0.00	0.44	0.00	0.26	0.05
Mean			**0.48**	**0.01**	**0.00**	**0.01**	**0.07**	**0.14**	**0.12**	**0.11**	**0.05**
Standard Deviation			**0.24**	**0.03**	**0.01**	**0.07**	**0.18**	**0.18**	**0.24**	**0.22**	**0.09**

Table 3.6 Distance (km) to nearest paved and unpaved roads from parturition sites of 27 female moose.

Year	Moose	Distance (km) to the Nearest Road	
		Paved Road	Unpaved Road
2013	M005	2.53	0.49
2013	M008	16.08	1.49
2013	M013	1.42	0.25
2013	M017	13.93	0.36
2014	M011	0.77	0.69
2014	M013	2.95	0.35
2014	M016	10.00	0.19
2014	M026	2.30	0.37
2014	M029	3.20	0.37
2014	M031	2.31	0.64
2014	M032	6.50	0.00
2014	M033	11.71	1.24
2014	M034	6.41	1.36
2014	M037	5.89	0.55
2014	M044	4.41	0.71
2014	M051	6.74	0.24
2014	M060	2.85	0.20
2014	M061	2.33	0.69
2014	M062	8.52	0.26
2015	M063	9.35	0.69
2015	M011	2.59	0.38
2015	M026	1.49	0.97
2015	M033	11.97	1.21
2015	M037	5.90	0.55
2015	M044	2.03	0.55
2015	M051	8.60	0.51
2015	M060	1.18	0.00
Mean		**5.70**	**0.57**
Standard Deviation		**4.19**	**0.39**

3.4.4.1. Selection Ratios

Selection ratios were calculated and Chi^2 Goodness-of-Fit tests indicated that habitat selection was significant ($p < 0.05$) and different than expected based on habitat availability in 2013 and 2014. Selection ratios and Bonferroni confidence intervals indicated that wetland and riparian habitat, trees and shrubs, and cropland were selected by female moose as parturition habitat in 2013 and 2014, while pasture and forages, developed and native grassland habitats

were avoided (Figure 3.9). In 2014, cropland could be broken down into pulses, oilseeds, cereals and minority crops and unseeded cropland to further describe the resource selection of 15 female parturient moose. Wetland and riparian habitat, trees and shrubs, were selected by moose as parturition habitat. Minority crops and unseeded cropland, and pulses were used in proportion to their availability. Pasture and forages, oilseeds, cereals, developed areas and native grassland were avoided (Figure 3.10).

A Chi^2 Goodness-of-Fit test indicated that the distance of parturition sites from paved roads was not significantly different than expected based on availability of sites. However, Bonferroni confidence intervals at 95% suggest that parturition sites that were 15 to 20 km from paved roads were selected by female moose as parturition habitat, while all other distances to the nearest paved road were used proportional to their availability (Figure 3.11). A Chi^2 Goodness-of-Fit test indicated that the distance of parturition sites from unpaved roads was not significantly different than expected based on availability of sites. However, Bonferroni confidence intervals at 95% suggest that parturition sites that were 1,200 to 1,600 m from the nearest unpaved road were selected by female moose. Parturition sites with the nearest unpaved roads in the range of 800 to 1,200 m were avoided. Parturition sites with the nearest unpaved roads in the range of 0 to 800 m were used proportional to their availability (Figure 3.12).

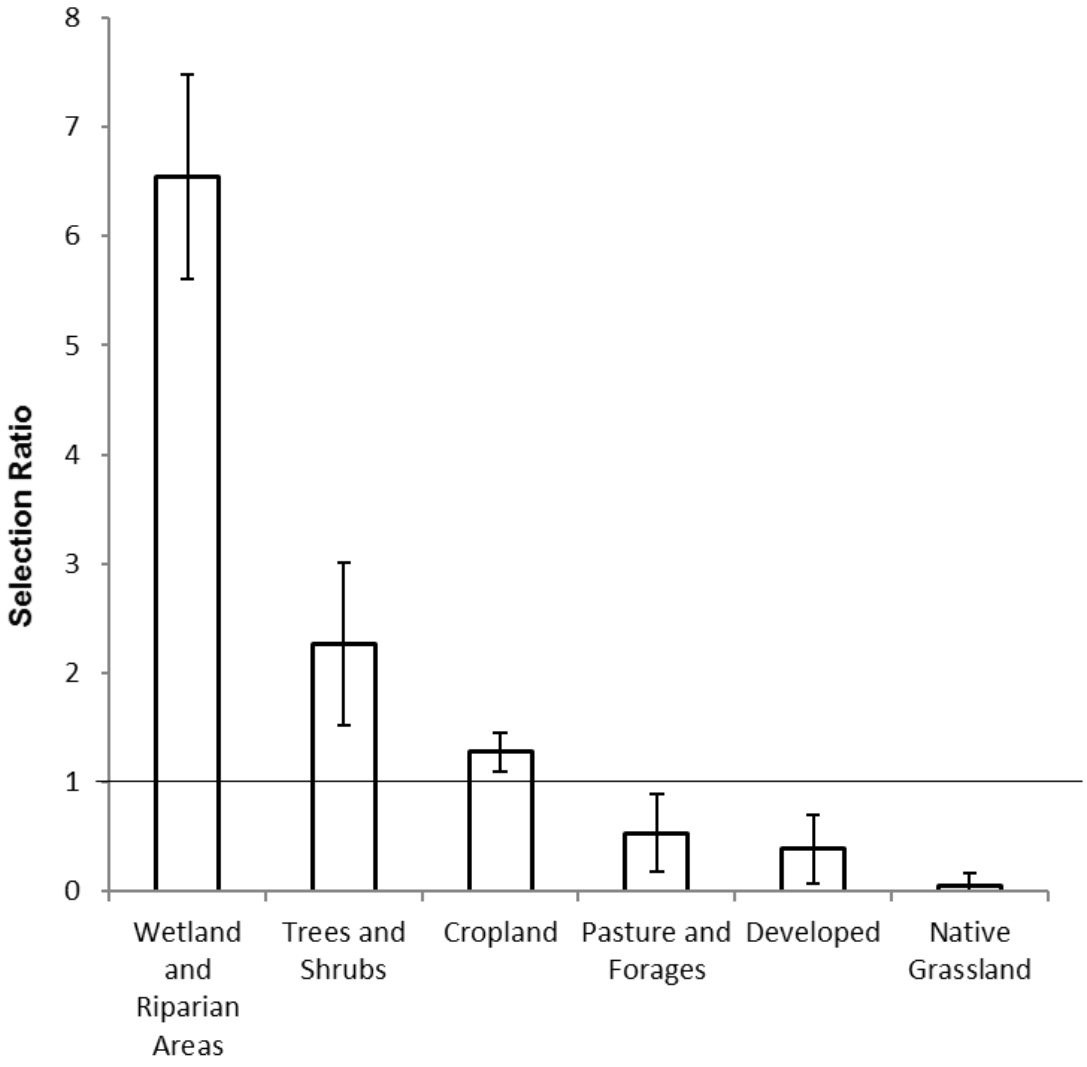

Figure 3.9 Selection ratios (95% CI) of the proportion of used and available habitat for GPS-collared female moose parturition sites in 2013, 2014, and 2015 (n = 27). All selection ratios are statistically significant at $p < 0.05$, indicating selection for wetland-riparian areas, trees and shrubs and cropland, and avoidance of other habitats. The solid horizontal line indicates habitat use is proportionate to availability (no selection nor avoidance).

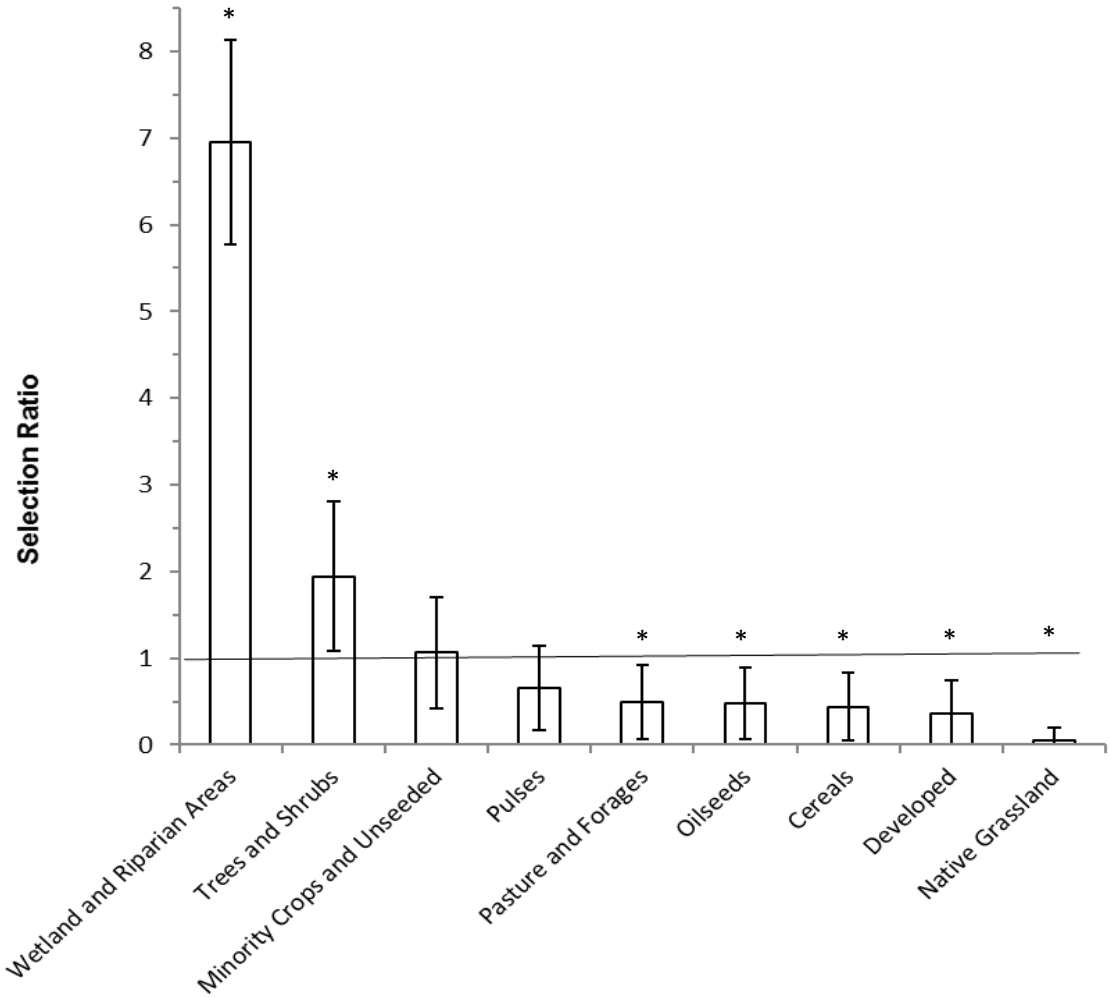

Figure 3.10 Selection ratios (95% CI) of the proportion of used and available habitat for GPS-collared female moose parturition sites in 2014 (n = 15). An asterisk signifies a statistically significant selection ratio with a Chi^2 Goodness-of-Fit test at $p < 0.05$. The solid horizontal line indicates habitat use is proportionate to availability (no selection nor avoidance).

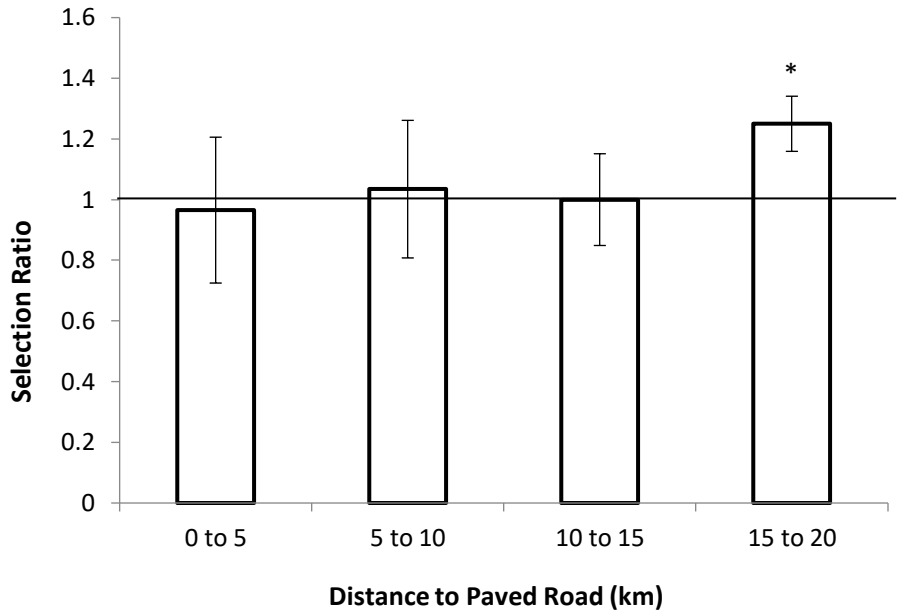

Figure 3.11 Selection ratios (95% CI) of used and available distance (km) to the nearest paved road for moose parturition sites (n = 27). A Chi^2 Goodness-of-Fit test indicated that selection was not different than expected based on availability. The asterisk indicates statistical significance with a 95% Bonferroni confidence interval. The solid horizontal line indicates habitat use is proportionate to availability (no selection nor avoidance).

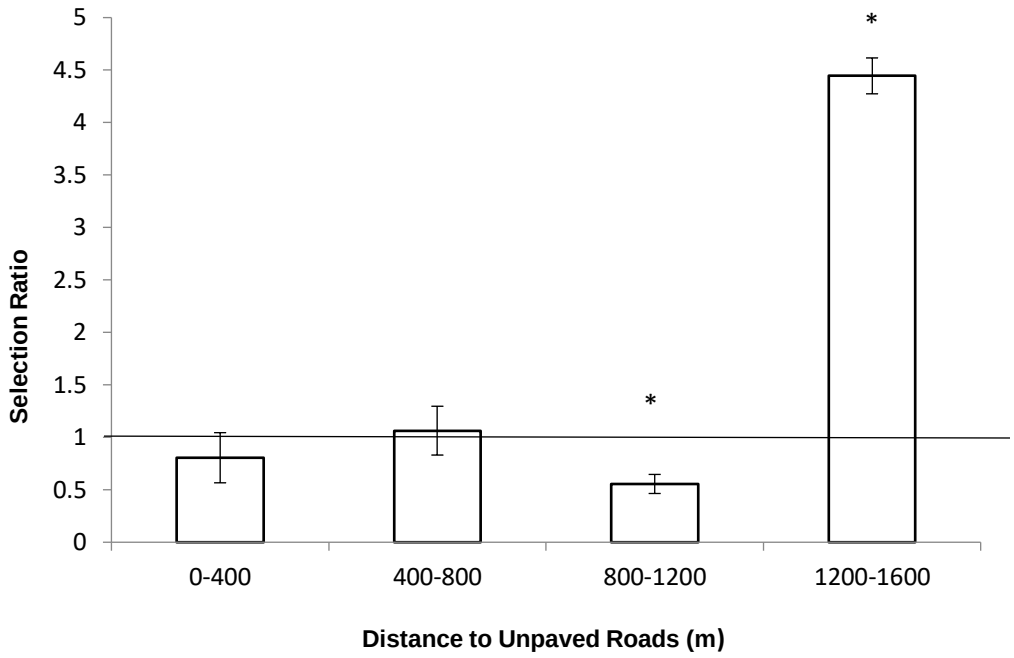

Figure 3.12 Selection ratios (95% CI) of used and available distance (m) to the nearest unpaved roads for moose parturition sites (n = 27). A Chi^2 Goodness-of-Fit test indicated that selection was not different than expected based on availability. The asterisk signifies statistical significance with a 95% Bonferroni confidence interval. The solid horizontal line indicates habitat use is proportionate to availability (no selection nor avoidance).

3.4.5. Habitat Selection during the First 20 Days Post-Parturition

Each of the land use covariate types had a minimum proportion value of 0 and maximum proportion value of 1 within the available buffers. This indicates that even covariates that were less common, such as native grassland, were available within the individual home ranges of all study animals up to 100% of the buffered locations. It is important when analysing resource selection to ensure that the covariates being studied are available within each individual study animal's home range.

The mean size of the 95% kernel home ranges of fourteen GPS-collared female moose with young during the first 20 days post-parturition was 8.15 km^2 (SD = 12.59; Table 3.7). Each individual parturient female had one to three clusters of activity in their calving season home range (Figure 3.13 and 3.14). The smallest home range size for a female moose during the first 20 days post-parturition was 0.03 km^2 while the largest was 45.01 km^2. The individual females with the smallest home ranges during the vulnerable calf period had twins (M013, M016), while the two females with the largest home ranges had single calves (M031, M017). When the mean 95% home range size was examined by separating females with twins or a single calf, the mean size of the home range of females with twins is 3.65 km^2 (SD = 3.83). The mean home range of females with single calves was 14.14 km^2 (SD = 17.78). Also, the individual female with the smallest home range (M013), had the highest proportion of wetland and riparian area within her home range at 0.92, while the two females with the largest home ranges (M031, M017) had the smallest proportions of wetland and riparian areas within their home ranges at 0.06 and 0.03, respectively (Table 3.7).

Table 3.7 Size and proportion of habitat variables within the 95% home range kernels of fourteen GPS-collared female moose with young during a period of 20 days post-parturition

Year	Moose	No. of Calves	95% Home Range Area (km^2)	Proportion of Habitat Variables within 95% Home Range							
				Wetland & Riparian	Developed	Native Grassland	Pasture & Forages	Cereals	Oilseeds	Pulses	Minority Crops and Unseeded
2013	M005	2	6.61	0.05	0.01	0.03	0.30	0.31	0.20	0.11	0.00
2013	M008	2	7.16	0.03	0.00	0.00	0.00	0.33	0.51	0.02	0.10
2013	M013	2	0.03	0.92	0.00	0.00	0.08	0.00	0.00	0.00	0.00
2013	M017	1	26.44	0.03	0.00	0.00	0.01	0.50	0.41	0.05	0.00
2014	M011	1	1.93	0.07	0.03	0.00	0.00	0.36	0.14	0.00	0.41
2014	M016	2	0.48	0.20	0.00	0.00	0.00	0.74	0.00	0.06	0.00
2014	M026	1	2.43	0.32	0.03	0.00	0.10	0.45	0.07	0.02	0.00
2014	M031	1	45.01	0.06	0.02	0.00	0.02	0.27	0.43	0.18	0.02
2014	M033	1	6.13	0.17	0.01	0.06	0.00	0.30	0.13	0.33	0.00
2014	M034	1	2.92	0.17	0.00	0.00	0.00	0.55	0.10	0.18	0.00
2014	M037	2	1.38	0.19	0.01	0.00	0.00	0.28	0.01	0.35	0.16
2014	M044	2	2.46	0.25	0.02	0.13	0.56	0.01	0.00	0.01	0.03
2014	M060	2	0.81	0.11	0.00	0.00	0.00	0.04	0.63	0.21	0.00
2014	M062	2	10.27	0.24	0.02	0.00	0.21	0.29	0.15	0.09	0.00
Maximum		2	45.01	0.92	0.03	0.13	0.56	0.74	0.63	0.35	0.41
Minimum		1	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean		1.57	8.15	0.20	0.01	0.02	0.09	0.32	0.20	0.11	0.05
SD		0.51	12.59	0.22	0.01	0.03	0.16	0.20	0.20	0.11	0.11

3.4.5.1. Model Development and Selection

The base model included 5 covariates and 1 random effect for individual moose (ID): Wetland + Oilseeds + Cereals + Native Grassland + Roads + (1 | ID). Removing any of these variables alone or in combinations did not improve the model. The parameters in the base model were tested for multicollinearity (i.e., correlations among one or more explanatory variables) using a Spearman's Correlation Coefficient Matrix (Table 3.8); all correlations were < |0.70| so all variables were retained (Dormann et al. 2013).

During habitat selection model development during the first 20 days post-parturition, pulses, trees and shrubs not associated with wetlands and riparian areas (i.e., those in farmyards and planted shelterbelts), and pastures and forages were not used because the parameter did not improve model fit (i.e., reduce the AIC value). Therefore, these habitat types were not considered important in habitat selection post-parturition.

Table 3.8 Spearman's Correlation Coefficient Matrix for base model parameters.

Parameters	Wetland & Riparian	Oilseeds	Cereals	Native Grassland	Roads
Wetland & Riparian		-0.171	-0.171	0.033	-0.012
Oilseeds	-0.171		-0.309	-0.143	-0.024
Cereals	-0.171	-0.309		-0.159	0.047
Native Grassland	0.033	-0.143	-0.159		0.145
Roads	-0.012	-0.024	0.047	0.145	

Next, I tested which, if any, non-linear (quadratic) terms of the base model parameters would improve the model fit. Quadratic terms describe the non-linear relationships between moose presence and habitat types. I tested the base model with each quadratic term alone and kept any terms that improved the model for further testing. I found that each of the nonlinear (quadratic) terms were informative and kept these in the model. Additionally, interactions between habitat types that provide either cover or forage, such as the interactions of Wetlands x Cereals, Wetlands x Oilseeds, and Wetlands x Native Grassland were also added to see if they improved the model. I tested these interactions, by added them to the top five best models (without interactions) to see how each of the three selected interactions alone, in combination, and all together changed the model. The interactions of Wetlands x Native Grassland and Wetlands x Oilseeds improved the model fit.

Thus, the top-ranked model for female moose with young during the first 20 days post-parturition included 5 linear parameters (wetland, oilseeds, cereal, native grassland, roads), all quadratic terms for those parameters, and the wetland x grassland interaction (Table 3.9). The AIC value was 13,177.85. Female moose selected for wetland and riparian areas, native grassland, cereal crops, and roads, while avoiding oilseed crops. Females accompanied by young most strongly selected for wetland and riparian areas (β [95% CI] = 0.716 [0.485, 0.946]) and native grassland (β [95% CI] = 0.457 [0.329, 0.585]), and against oilseeds (β [95% CI] = –0.252 [–0.400, –0.103]; Table 3.10). Predictive success for the top model, estimated from k-fold cross validation, was r_s = 0.993 (SE = 0.001).

Model No. 2 can also be considered a well-supported model, with ΔAIC = 0.18, = one additional degree of freedom and r_s = 0.995 (SE = 0.001; Table 3.9). The difference in parameters between Model No. 1 and No. 2 is the substitution of an interaction term of Wetland

× Native Grassland in Model No. 1 with two interaction terms of Wetland × Cereals and Wetland × Oilseeds in Model No. 2. The same selection patterns are observed in Model No. 2 where female moose selected for wetland and riparian areas, native grassland, cereal crops, and roads, while avoiding oilseed crops. As with Model No. 1, female moose most strongly selected for wetland and riparian areas (β [95% CI] = 1.350 [1.246, 1.453]) and most strongly against oilseeds (β [95% CI] = –0.675 [–0.865, –0.484]; Table 3.11). However, in contrast to Model No. 1, the selection for cereals (β [95% CI] = 0.342 [0.250, 0.433]) was slightly stronger than the selection for native grassland (β [95% CI] = 0.251 [0.131, 0.371]).

The most parsimonious model (Model No. 1) was used in the resource selection function. The results from the resource selection function indicate that only 10% of the area within the home ranges of parturient females is considered highly selected habitat with high probability of moose use, while 48% of the area has a low probability of habitat use (Figure 3.13 and 3.14).

Table 3.9 Degrees of freedom (df), Akaike's Information Criterion (AIC), ΔAIC, and predictive ability (r_s) for the top five models for GPS-collared female moose with young during the 20 days post-parturition period in south-central Saskatchewan, 2013–2014.

Model No.	Model	df	AIC	ΔAIC	r_s (SE)
1	Wetland + Wetland^2 + Oilseeds + Oilseeds^2 + Cereals + Cereal^2 + Native Grassland + Native Grassland^2 + Roads + Roads^2 + (1 | ID) + Wetland × Native Grassland	13	13,177.85	0.00	0.993 (0.001)
2	Wetland + Wetland^2 + Oilseeds + Oilseeds^2 + Cereals + Cereal^2 + Native Grassland + Native Grassland^2 + Roads + Roads^2 + (1 | ID) + Wetland × Cereals + Wetland × Oilseeds	14	13,178.03	0.18	0.995 (0.001)
3	Wetland + Wetland^2 + Oilseeds + Oilseeds^2 + Cereals + Cereal^2 + Native Grassland + Native Grassland^2 + Roads + Roads^2 + (1 | ID) + Wetland × Oilseeds	13	13,183.52	5.67	0.993 (0.001)
4	Wetland + Wetland^2 + Oilseeds + Oilseeds^2 + Cereals + Cereal^2 + Native Grassland + Roads + (1 | ID) + Wetland × Cereals + Wetland × Oilseeds	12	13,184.11	6.26	0.995 (0.001)
5	Wetland + Wetland^2 + Oilseeds + Oilseeds^2 + Cereals + Cereal^2 + Native Grassland + Roads + (1 | ID) + Wetland × Oilseeds	11	13,192.72	14.87	0.988 (0.001)

Table 3.10 Parameters from the top model for habitat selection by female moose with young during the 20-days post-parturition period in south-central Saskatchewan, 2013–2014. Regression (β) coefficients and their associated 95% confidence intervals (CI) are shown.

		95% CI	
Variable	**β**	**Lower**	**Upper**
Intercept	0.716	0.485	0.946
Wetland	1.164	1.091	1.237
Wetland^2	–0.481	–0.532	–0.429
Oilseeds	–0.252	–0.400	–0.103
Oilseed^2	0.076	0.006	0.145
Cereal	0.161	0.073	0.249
Cereal^2	–0.300	–0.376	–0.225
Native Grassland	0.457	0.329	0.585
Native Grassland^2	–0.089	–0.111	–0.067
Roads	0.264	0.204	0.323
Roads^2	–0.038	–0.076	0.001
Wetland × Native Grassland	–0.453	–0.548	–0.357

Table 3.11 Parameters from Model No. 2 for habitat selection by female moose with young during the 20-days post-parturition period in south-central Saskatchewan, 2013–2014. Regression (β) coefficients and their associated 95% confidence intervals (CI) are shown.

		95% CI	
Variable	**β**	**Lower**	**Upper**
Intercept	0.515	0.278	0.752
Wetland	1.350	1.246	1.453
Wetland^2	–0.395	–0.456	–0.335
Oilseeds	–0.675	–0.865	–0.484
Oilseed^2	0.603	0.462	0.744
Cereal	0.342	0.250	0.433
Cereal^2	–0.599	–0.711	–0.487
Native Grassland	0.251	0.131	0.371
Native Grassland^2	–0.022	–0.038	–0.006
Roads	0.247	0.188	0.307
Roads^2	–0.028	–0.067	0.011
Wetland × Cereals	–0.182	–0.313	–0.052
Wetland × Oilseeds	0.771	0.601	0.942

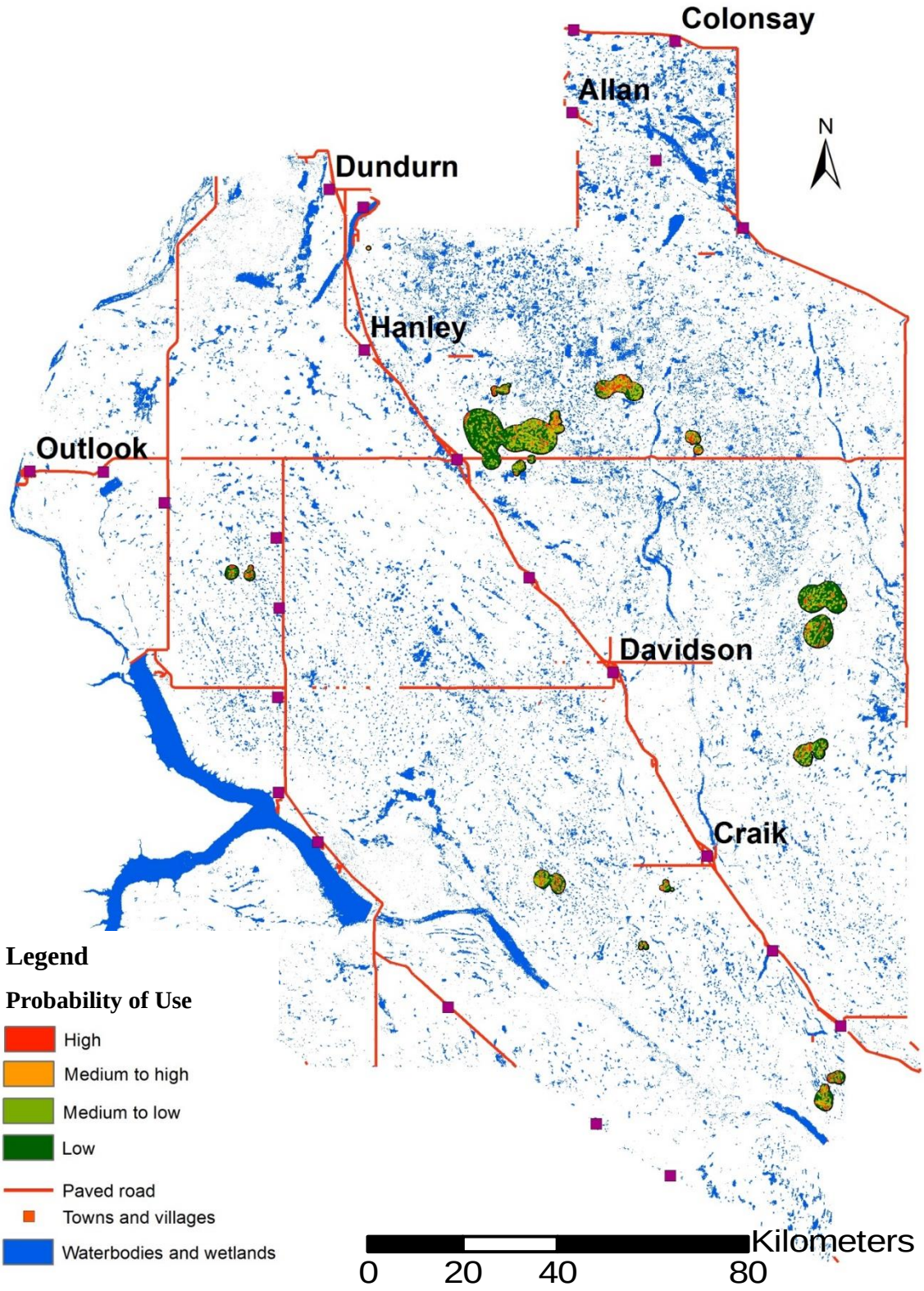

Figure 3.13 Resource selection function based on use-availability data of GPS-collared female moose with young 20 days post-parturition within 95% kernel home ranges (n = 14).

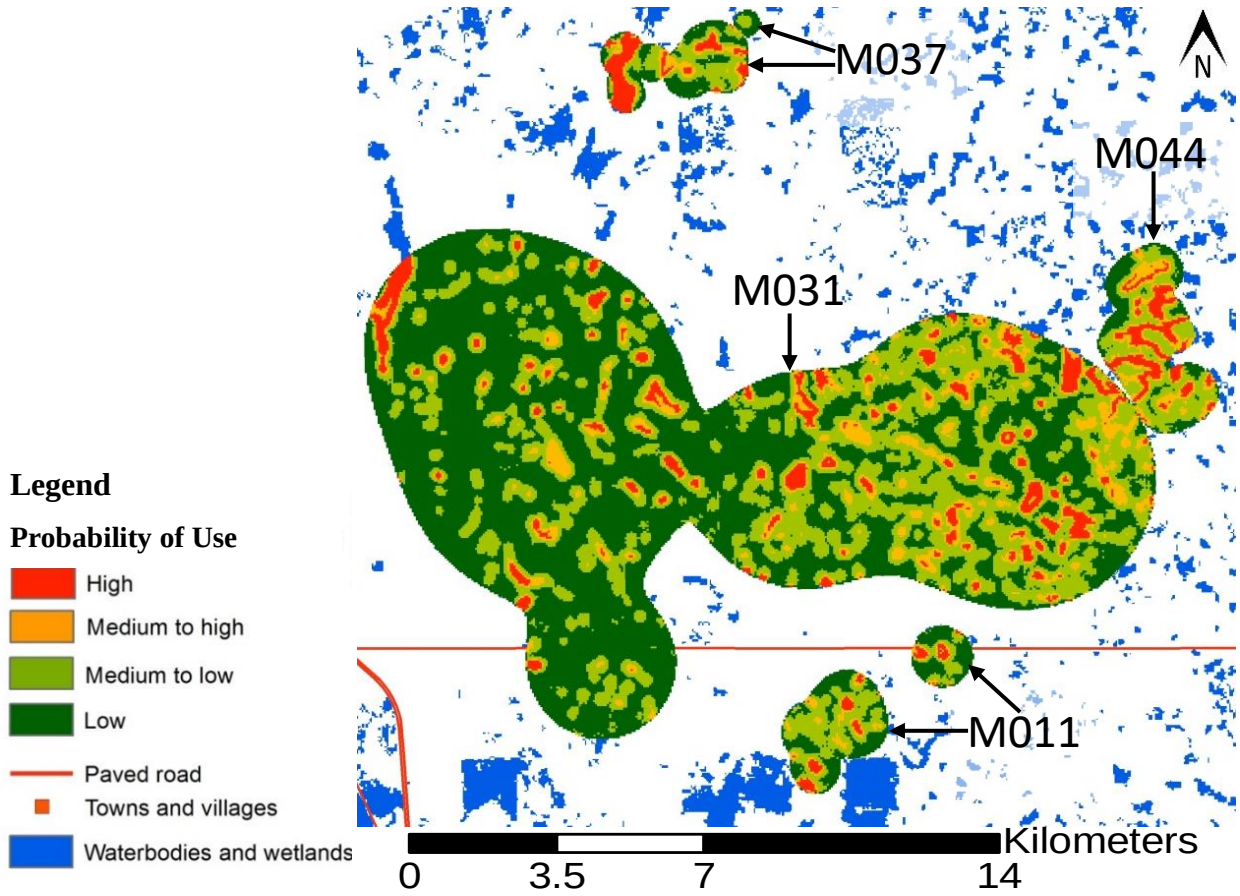

Figure 3.14 Resource selection function based on use-availability data of GPS-collared female moose with young 20 days post-parturition showing four females' 95% kernel home ranges.

3.5. Discussion

3.5.1. Pregnancy Rates

In most moose populations, ovulation, conception, and pregnancy rates are not influenced by habitat quality, except in severely poor conditions (Schwartz 2007). Ovulation rates are consistently high in adult females varying from 71 to 100% (Schwartz 2007). Pregnancy or conception rates of adult females are also consistently high throughout North America and average 84.2% (Boer 1992). A pregnancy rate of 94% for females aged 2 to 11 years old was observed in the Saskatchewan boreal forest with 25% of pregnant moose carrying twins (Haigh et al. 1982). The pregnancy rate of GPS-collared female moose in my study was 84% in both 2013 (n = 16/19) and 2014 (n = 16/19). These pregnancy rates suggest that the moose population in the study area is comprised of reproductively healthy females with habitat, forage, and male ratios that support conception.

3.5.2. Timing and Location of Parturition Sites

In my study, the mean parturition date for all years combined of the 27 female moose was May 21 with a range from May 13 to May 29. The seasonal timing of moose parturition and associated movement patterns observed in my study are consistent with results of other studies in North America (Sigouin et al. 1997, Testa et al. 2000a, Testa et al. 2000b, Musante et al. 2010, McLaren et al. 2017). McLaren et al. (2017) confirmed that using localized movement of GPS collar data was an accurate method to determine parturition sites, as these sites aligned with VIT expulsion locations. In my study I used localized clustering and movement rates to determine parturition sites. At no other time during May and June of each year, were such localized movement patterns present in the GPS collar data.

There is limited research on moose calving habitat in the southern limit of the species range (McLaren et al. 2017). My study area is particularly unique in that it represents a southern range expansion, but also occurs in a highly fragmented landscape with 70% of the land cover being annual cropland (Agriculture and Agri-Food Canada [AAFC] 2013, 2014a). In my study, moose parturition sites contained wetland and riparian habitat. Within the study area, there was only approximately 8.9% of wetland and riparian habitat available. The selection of wetland and riparian habitat and proximity to water for parturition has been observed in other studies

(Altmann 1963, Poole et al. 2007). Conversely, McLaren et al. (2017) found that moose selected calving sites that were open rocky areas and open grass meadows. These open areas may be selected because wind from open areas creates relief from mosquitoes and black flies or as a part of an anti-predator strategy (McLaren et al. 2017). Parturient female moose in my study area are likely using wetland and riparian habitat type for both forage, and escape and thermal cover.

Although there are relatively few predators of moose calves in the study area, human disturbance is high with a rural network of roads every two miles (3.2 km) north and south and every one mile (1.6 km) east and west. Furthermore, almost every quarter section that is annual cropland (70% of the study area) would be seeded to an annual crop between late April to early June using large farm equipment. The agronomic practice of applying agro-chemicals to cropland results in further anthropogenic disturbance during the calving season. During the spring season when farmers and ranchers are highly active on the landscape, female moose with young select escape cover in remnant wetland and riparian habitat that is often surrounded by annual cropland.

Native grassland and pasture and forages are used in livestock production. In my study area, the predominant livestock type is beef cattle. Beef cattle are often put into native grassland or other pastures for the grazing season, beginning in May and June. In these areas, cattle congregate at wetlands and treed areas. Moose seek isolation during the calving season and the potential for interaction with cattle likely contributes to moose avoidance of native grassland and pasture and forages during parturition.

3.5.3. Moose Calf Surveys

The rate of twinning in moose varies considerably spatially and temporally and is considered an indicator of nutrition, habitat quality, and carrying capacity (Gasaway et al. 1992, Franzmann and Schwartz 1985). Twinning rates in the range of 0 to 25% have been found in populations considered near or above their carrying capacity, while higher twinning rates suggest the population is below the landscape's carrying capacity (Gasaway et al. 1992). During a long-term study in Alaska from 1976-1985, pregnancy and twinning rates averaged 81% and 38% respectively (Ballard et al. 1991). Of the pregnant females in my study that were observed during calf surveys with 1 or 2 calves, twinning rates were 66.7% in June 2013 (n = 6/9) and 45.5% in June 2014 (n = 5/11; Figure 3.8). These results represent a reproductively sustainable population

that is perhaps increasing and currently below the carrying capacity of the area. Moderate productivity, as seen in the south-central Saskatchewan moose population, likely suggests a combination of adequate nutrition, and balanced adult sex ratios (Albright and Keith 1987).

Due to the small sample sizes of twin and single calves that were observed in both June and September of each year, I cannot confirm reliably if twin or single calves experience different mortality rates. Testa et al. (2000b) found different survival rates between twins and single moose calves, but calves in their study area experienced high predation rates from brown bears. Due to the relative lack of moose calf predation within my study area, I suspect that twin and single calf survival would not be significantly different in my study area.

Predation is often the primary cause of moose calf mortality and can account for up to 83% mortality (Ballard et al. 1991, Gasaway et al. 1992). Common predators of moose, such as black bears and cougars, could occur within my study area in low numbers. Also, it is possible that coyotes, which are commonly observed within the study area, prey on moose calves depending on the defensive behaviour of the adult female moose. Calf survival is lowest in the first month of life (Hauge and Keith 1981). The majority of females whose movement rates demonstrated that parturition occurred, had calves survive through the first 20 days post-parturition. This high survival rate suggests that calf mortality due to predation is low within the study area.

M051 and M032 were two female moose that experienced parturition movement rates, but subsequently lost their calves before summer calf surveys. In 2014, M051 lost her young but was documented as reproducing again in 2015. M032 lost her young in 2014 after parturition occurred in a wetland approximately 80 m from an unpaved road. Both females calved after the mean parturition date of May 21 (Table 3.4). It is unknown if habitat or another factor, such as weather, resulted in calf mortality in either of these study animals.

Again, due to small sample size, I was unable to determine the ability of individual moose in this expanding population to have successful reproduction or twinning over consecutive years. Only two females (M013, M016) were observed during the calving seasons of two consecutive years. In 2013, M013 had twins and in 2014, she was observed with one calf. In 2013, M016 was observed with one calf, and in 2014 the female was observed with twin calves. It is interesting that neither individual was observed with twins in consecutive years, but that both females did reproduce in consecutive years.

3.5.4. Habitat Selection during Parturition

Wetland and riparian habitat with trees and/or tall shrubs occurred within each of the 27 moose parturition sites. The mean wetland size was 3.45 ha (SD = 4.10; Table 3.4). Of the 27 parturition sites, 77.8% (n = 21) included cropland within the 100 m buffer (Table 3.4). These results demonstrate the importance of existing semi-permanent and permanent wetlands within cropland to parturient female moose (Table 3.4, Figure 3.9). Retaining these wetlands despite increasing economic pressure to convert them to cropland is particularly important for the persistence of this expanding moose population.

Selection ratios indicated that wetland and riparian habitat, trees and shrubs, and cropland were selected by female moose as parturition habitat, while pasture and forages, developed and native grassland habitat were avoided (Figure 3.9). During late spring and early summer when the moose calving season occurs, moose likely still have thick winter hair coats to shed and are becoming acclimatized to increasing temperatures. This may result in all moose, especially adult females with the metabolic challenge of nursing often multiple young, to select habitats that aid in thermoregulation, including wetlands with trees and shrubs. When cropland was broken into specific crop types for parturition selection ratios in 2014, similar patterns emerged (Figure 3.10). Wetland and riparian habitat, and trees and shrubs were selected, while pasture and forages, developed and native grassland habitat are being avoided. However, specific crops showed different selection for parturition sites. Pulses, as well as minority crops and unseeded cropland were used in proportion to availability (i.e., not selected or avoided), while oilseeds and cereals were avoided. It is possible that crop types do not provide forage to moose in May during parturition and therefore are not being used and not an important factor in selecting parturition sites. However, most cropland seeded in late April and early May would have germinated and grown into palatable and nutritious plants during the moose calving season. Considering the uncertainty around available food resources from crop types at the time of parturition, moose selection or avoidance of specific crop types is considered inconclusive (Figure 3.10). Native grassland, as well as pasture and forages habitat types would have vegetation remaining from the previous year's growth at the time of parturition. As well, these habitat types would have new growth present during the moose calving season.

The mean distance to the nearest paved and unpaved roads from parturition sites was 5.70 km (SD = 4.19) and 0.57 km (SD = 0.39), respectively (Table 3.6). There was a large amount of

individual variation in distance to the nearest paved road from parturition sites with a range of 0.77 to 16.08 km (Table 3.6). This likely reflects the lower prevalence of paved roads in the study area, compared to unpaved roads which typically occur in a rural network of roads every 2 miles (3.2 km) north and south and one mile (1.6 km) east and west. Parturition sites that were 15 to 20 km from paved roads were selected by moose as parturition habitat, while all other distances to the nearest paved road were used proportional to their availability (Figure 3.11). Female moose were selecting parturition sites farther away from paved roads.

Interpreting the effect of unpaved roads on the selection of parturition sites was less clear (Figure 3.12). Parturition sites 1,200 to 1,600 m from an unpaved road may have been selected. These sites are farthest from unpaved roads which represents less human disturbance. Parturition sites 0 to 800 m from an unpaved road were used proportional to their availability, which could be influenced by the prevalence of unpaved roads in the study area. Many large wetlands with trees and shrubs that remain on the landscape are close to unpaved roads. When water from smaller wetlands has been drained off cropland in an intentional effort to increase productive acres, water congregates near linear barriers such as unpaved roads. However, selection for unpaved roads and the habitat types near them was not observed. Parturition sites 800 to 1,200 m from the nearest unpaved road may have been avoided. There was only one used parturition site located in this distance range from an unpaved road. The reason for this potential avoidance is unclear. A larger sample size may have changed or helped bring clarity to the selection patterns around unpaved roads that were observed in my results.

3.5.5. Habitat Selection during the First 20 Days Post-Parturition

The top-ranked model for female moose with young during the first 20 days post-parturition included 5 linear parameters (wetland, oilseeds, cereal, native grassland, roads), all quadratic terms for those parameters, and the wetland x native grassland interaction (Table 3.8). During the first 20 days post-parturition period, female moose selected for wetland and riparian areas, native grassland, cereal crops, and roads, while avoiding oilseed crops. Wetland and riparian habitat, including trees and shrubs, was selected for by female moose for both parturition sites and during the first 20 days post-parturition.

Native grassland, as well as pasture and forages were avoided during parturition. However, native grassland was selected for during the first 20 days post-parturition. During

model development to characterize habitat selection post-parturition, pasture and forages were not used in the model, as the habitat type did not improve the AIC value of the model. Therefore, pasture and forages were not considered important in habitat selection during the post-parturition period. These changes in selection from parturition to post-parturition could be due to a number of factors including: 1) cattle being moved into native grassland and tame pasture around the timing of parturition (mid-May) and reflect the sensitivity of parturient moose to disturbances from both humans and livestock; and 2) the increasing food availability from grassland as the growing season progresses. Although there is anecdotal evidence of moose and cattle occupying the same areas, cattle would have been absent from native grassland and tame pasture since the previous growing season.

Pulses were used in proportion to availability (i.e., not selected or avoided) during parturition. During model development to characterize habitat selection post-parturition, pulses were not used in the model as the habitat type did not improve the AIC value of the model. Therefore, pulses were not considered important in habitat selection during or after parturition. Oilseeds and cereals were avoided during parturition; however, cereals were selected for post-parturition. This change in selection patterns for cereals could reflect the increasing food availability from cereal crops as the growing season progresses. Although anecdotal evidence supports moose consumption of oilseed crops such as canola, canola forms a dense canopy during the growing season, which would likely impact the mobility of young calves. I have observed adult moose without calves in canola crops eating the canola plants. Laforge et al. (2017) found that the probability of moose selection, as indicated by crop damage, increased with cover of pulses, oilseeds, and alfalfa. Laforge et al. (2016) found that female moose in farmland selected for wetland and forest, cereals, and oilseeds, while avoiding pulses and developed areas in summer (July to September). Of the crop types examined, moose did show slightly stronger selection for cereals than oilseeds or pulses (Laforge et al. 2016). Whether these females had calves was not provided in Laforge et al. (2016), but if calves were present, they would have been older and therefore more mobile and less vulnerable. Regardless, there are some similar selection patterns observed between these females in July to September and the parturient moose in my study area during the first 20 days post-parturition, overlapping with May and June. The main difference in selection patterns is that oilseeds and pulses were not selected for during my study. This can be partially explained by a combination of factors

including the actual availability of the newly seeded crops in May and early June, the mobility of young calves, and the importance of cover vs. forage during parturition and the first 20 days post-parturition.

Trees and shrubs not associated with wetlands, such as those in farmyards and planted shelterbelts were examined. However, this habitat type did not improve the AIC score of the predictive model and was therefore not included in the top model. The human activity in farmyards that are inhabited or used as bin yards may influence moose habitat selection. Shelterbelts tend to be linear tree rows with limited cover in cropland, which tends to have high human activity during the growing season. Wetlands and riparian areas including trees and shrubs were strongly selected for both parturition and post-parturition habitat. Perhaps the lack of water in farmyards and shelterbelts resulted in the habitat type not being important in prediction of moose presence.

Interaction terms in models suggest a trade-off between selection for quality within a heterogenous habitat type and disadvantages associated with competition or predation risk (McLoughlin et al. 2006). In the top model an interaction of wetlands and native grassland improved the model, suggesting a trade-off between the two land cover types. The interaction of wetlands and native grassland was selected by female moose with young calves. As individual parameters both wetlands and native grassland were selected for; however, the interaction term suggests that there is a trade-off or threshold that is desirable between these to land cover types. The interaction of these two land cover types provides a mixture of forage, water, and shelter for thermoregulation. Additionally, this combination of habitat types would likely be subject to less human activity than a wetland and annual cropland combination.

Female moose selected parturition sites further away from paved roads while using sites near unpaved roads in proportion to their availability. In the top model, female moose weakly selected for roads (combined paved and unpaved roads) during the first 20 days post-parturition period. Moose have been shown to select for roads at intermediate scales (Rempel et al. 1997) while avoiding them at small scales (Dussault et al. 2007). Road development and subsequent management changes habitat and can make these areas more attractive to wildlife (Child 2007, Beyer et al. 2013). Predators often avoid roads due to human hunting, but in this landscape without established moose calf predators, the selection of roads is unlikely to be result of predator avoidance. Cropland drainage can result in large wetlands with trees and shrubs close to

unpaved roads. As water from smaller wetlands is drained off cropland in an intentional effort to increase productive acres, water congregates near linear barriers such as unpaved roads. Wetland and riparian habitat in proximity to roads may explain the weak selection by female moose for roads during the first 20 days post-parturition.

Across the global distribution of moose, the size of moose home ranges varies considerably and is likely influenced by habitat quality (Snaith and Beazley 2004). A home range is the area that an animal moves in when performing its normal activities during a specific, biologically meaningful period of time (Morris 1988, Harris et al. 1990). The mean size of the 95% kernel home ranges of fourteen GPS-collared female moose with young during the first 20 days post-parturition was 8.15 km^2 (SD = 12.59; Table 3.6). The smallest home range size for the 20-day post-parturition period was 0.03 km^2 while the largest was 45.01 km^2. When the mean 95% home range size was examined by separating females with twins or a single calf, the mean size of the home range of females with twins was 3.65 km^2 (SD = 3.83). The mean home range of females with single calves was 14.14 km^2 (SD = 17.78). Each individual parturient female had one to three clusters of activity in their calving season home range (Figure 3.13 and 3.14). This implies that suitable habitat was highly fragmented in the study area and that female moose with vulnerable young would have to travel between suitable habitat patches where they would spend 95% of their time. The results of this study suggest that female moose with twin calves have smaller 95% home ranges when calves are most vulnerable during the first 20 days post-parturition. Generally, females with twins and smallest home ranges also had higher proportion of wetland and riparian habitat than females with single calves and larger home ranges (Table 3.6). My study cannot confirm whether females with higher quality habitat (i.e., more wetland and riparian habitat) in their home ranges are then able to have twins, or if females that have twins then select and remain in higher quality habitat. However, twin calves are typically smaller in birth weight compared to single calves (Schwartz and Hundertmark 1993), and therefore, are likely less mobile and more vulnerable to predators and environmental conditions. Females with twins may select and remain in areas of high-quality habitat due to high nutritional demands of lactation and additional movement restrictions caused by twin calf mobility.

Parker and Gillingham (2007) found that seasonal ranges of female moose were typically smallest during the calving season at 18 km^2 and were up to 7 times larger during the summer season. The mean size of the 95% kernel home range in my study was considerably smaller at

8.15 km^2 (SD = 12.59; Table 3.6). Several other studies have confirmed that female moose with young use smaller home ranges than other age/sex classes of moose (LeResche 1974, Ballard et al 1991, van Beest et al. 2011). Other studies have found mean summer home ranges for female moose of 12.6 km^2 to 23.9 km^2 (Hauge and Keith 1981, Cederlund and Okarma 1988, Parker 2003). Within an overlapping study area in Saskatchewan, female moose had mean summer home ranges (95% kernel home range) with standard deviations of 34.6±19.4 km^2 (Brook et al. 2016). Summer home ranges ranged from 6.3 to 78.8 km^2. Annual home ranges were a mean of 227.7 km^2 and ranged in size from 33 to 1,373 km^2 (Brook et al. 2016). In the fragmented habitat, home range fidelity was quite low between summer and winter ranges (Brook et al. 2016). My study calculated the 95% home ranges of female moose with young 20 days post-parturition; therefore, it is understandable that the mean home range size that I observed would be smaller than mean home range sizes observed in studies that examined the entire summer season. As moose calves become more mobile with increasing age over the summer, the pair increases their movement and the size of their home range.

Adequate quantities of useable resources are required to sustain animal populations (Manly et al. 2002). Although stable habitats are necessary for supporting moose populations between transient habitats, large population increases generally occur when transitory habitats increase (Peek 1974). It is possible that the agricultural cropland of the Moist Mixed Grassland Ecoregion in Saskatchewan represents a transitory habitat for moose, allowing for a range expansion, particularly during a wet cycle.

Contrary to the theory of temperature-dependant habitat selection for moose, Lowe et al. (2010) did not observe differences in habitat use of female moose relative to accepted thermoregulation thresholds of -5^oC in winter and 14^oC in summer. In forested habitat the need for thermal cover may not be as easily observed due to the readily available shade that trees provide. However, in the agricultural-dominated landscape of south-central Saskatchewan, wetlands and riparian habitat cover were selected during parturition and post-parturition, while more open habitat types of crop types were either avoided or selected less strongly. The results of this study show the importance of wetland and riparian habitat, as it provides a suitable combination of forage, water, thermal cover, and hiding cover for female moose with neonatal young.

The results from the resource selection function indicate that only 10.2% of the area within the home ranges of parturient females is considered highly selected habitat with high probability of moose use, while 47.8% of the area has a low probability of habitat use by post-parturient moose (Figure 3.13 and 3.14). Nevertheless, the survival of calves during this period suggests that parturition and post-parturition habitat is not acting as a sink for the population. Because a low amount of highly selected habitat is found in actual home ranges that parturient females are using during a critical reproductive life stage (i.e., parturition and with neonatal young), the importance of this habitat cannot be understated. These results demonstrate the importance of existing semi-permanent and permanent wetlands within cropland to parturient female moose (Table 3.3, Figure 3.9). Retaining these wetlands despite increasing economic pressure to convert them to cropland is particularly important, perhaps even critical, for the persistence of this expanding moose population.

Chapter 4: Summary and General Discussion

4.1. Thesis Purpose

The purpose of this thesis research was to (1) determine reproductive measures, such as pregnancy and twinning rates, of adult female moose in a population that has recently expanded into farmland areas of Saskatchewan, (2) identify the general calving period of this moose population and estimate specific parturition sites of individual moose, (3) quantify the strength of selection for specific habitat types by female moose for use as parturition sites, (4) estimate home range size for post-parturient female moose with young, and (5) characterize resource selection of adult female moose during the period of 20 days post-parturition when calves are most vulnerable.

4.2. Hypotheses Revisited

I hypothesized that adult female moose will primarily select for high quality hiding cover during parturition. I hypothesized that post-parturient female moose with young calves will select both hiding cover and high quality foraging habitats. I hypothesized that habitat selection by parturient and post-parturient adult female moose would be influenced by wetlands with tree and shrub cover and distance from roads. I hypothesized that wetlands and their associated riparian areas, and trees and shrubs not associated with wetlands would be of importance to female moose habitat selection. Although trees and shrubs not associated with wetlands and riparian areas were important in the selection of parturition sites, they were not considered an important factor in habitat selection post-parturition. Trees and shrubs not associated with wetlands, such as those in farmyards and planted shelterbelts were examined. However, this habitat type did not improve the AIC score of the predictive model and was therefore not included in the top model.

I hypothesized that native grassland and pasture and hay land (i.e., forages) would also be of importance to female moose with neonates due to the lower amount of anthropogenic activity compared to annual cropland. Additionally, the early availability of forage on native grassland and in pasture and hay land compared to cropland, might also act as an attractant for female moose with young. Wetlands with tree and shrub cover and distance to roads were important factors in both selection of parturition sites and post-parturition habitat. The selection of other habitat types changes between parturition and post-parturition. During parturition parturient

female moose strongly selected hiding cover, while post-parturition there was a trade-off between selecting hiding cover and forage. Native grassland and pasture and forages were avoided during the selection of parturition sites; however, native grassland was considered an important factor in habitat selection post-parturition.

I hypothesized that reproductive measures of female moose will suggest that farmland habitat is of low quality, based on the relative lack of traditional moose habitat of forest and wetlands. Reproductive measures such as pregnancy and twinning rates were consistent with North American averages and did not indicate the presence of low quality habitat.

4.3. Study Limitations and Proposed Future Research

The largest study limitation for this research was the number of GPS collars that were deployed and the length of time in which they reliability worked. Unfortunately, after only 18 months from the time of the 2013 collar deployment, all 19 collars had failed to transmit location data and VHF signals could not be heard from the ground or airplane. Of the 20 collars deployed in 2014, three failed or were not reliably working within a month of deployment. An additional six collars failed within the first year of deployment and only eight of the 2014 collars could be used for the parturition site analysis in 2015.

Other study limitations include a degree of uncertainty surrounding twinning rates. Calf survival and twinning rates could have been affected by calf mortality prior to calf surveys being conducted each spring after the 20 days post-parturition period. Waiting until June of each year to conduct moose calf surveys prevented disturbing parturient females, which could have biased habitat selection and caused abandonment of neonatal calves. Ultrasounds could have been conducted on female moose at the time of capture to determine the number of calves each female was pregnant with. However, conducting ultrasounds would have increased the time duration of handling for each individual moose during collaring.

If the sample size of adult females with calves for this research had been larger it would be desirable to compare the habitat selection of adult females whose calves survived with the habitat selection of females whose calves did not survive. In this research, I was unable to determine daily mortality rates for calves due to a lack of daily calf surveys and GPS movement data for calves. Depending on the impact that GPS-collaring has on moose calf survival, this could be a direction for future research. Future research in the study area should examine calf

mortality, as well as adult and calf mortality through hunting and the winter season. Future studies should take a long-term approach and should examine the potential connections between habitat selection, habitat quality, adult moose health and calf survival. Habitat selection can be different when measured at different spatial scales (Laforge et al. 2015). Examining spatial scales larger than 100 m may have shown additional habitat selection patterns. Future research could examine habitat selection at different spatial scales.

Additional considerations for future research includes further examination of habitat in regards to management or human use and movement rates. Cattle use of pastures and native grassland could have been documented to determine the extent of habitat use overlap with female moose. Cattle may attract or exclude female moose with young from these habitats. Farmyards and acreages were not classified as developed areas in the AAFC land cover layer. These areas could have been placed into a separate habitat category and classified based on if the area had an active human resident or not. Movements rates could also be examined to determine if movement rates and habitat use changed based on time of day and temperature.

Diet selection of moose inhabiting farmland should be a focus of future research. This research would determine the extent to which moose are consuming annual crops or other non-browse food items in the agriculture dominated landscape. The results of diet selection research would determine whether crop inventories and damage reports are truly beneficial to wildlife managers in managing this moose population and in setting annual hunting quotas. This research could also be important to Saskatchewan Crop Insurance Corporation (SCIC) as this corporation is responsible for assessing wildlife damage claims on crops and paying insurance for damage (SCIC 2019).

An RSF analysis can be used to evaluate the impact of habitat changes (Manly et al. 2002). In May 2011, 2012, 2013, 2014 and 2015, spring water levels in wetland basins in southern Saskatchewan were 57%, 32%, 39%, 33%, and 24% higher than the long-term average, respectively (U.S. Fish and Wildlife Service 2011, 2012, 2013, 2014, 2015). This study was completed during a time when the prairies in Saskatchewan were receiving above average moisture leading to above-average spring water levels in wetlands. Future studies should be completed during below-average moisture conditions (i.e., during drought conditions) to determine if moose reproductive success and habitat selection is affected. A long-term study would be able to examine lifetime reproductive success, site fidelity to parturition sites and

seasonal and annual home ranges. Although the RSF developed in this study was used to determine highly selected habitat post-parturition, it should not be extrapolated beyond this study area due to the small sample size and the effect of individual moose on the analysis. Future RSF results based on a larger sample of moose could be extrapolated and used to estimate the carrying capacity and population density of moose within this agriculture-dominated area. The expanding moose population in this agricultural study area should be a focus of future research, especially since moose populations are currently in decline throughout much of their northern range.

4.4. Research Summary

The pregnancy rate of GPS-collared female moose in my study was determined to be 84% in both 2013 (n = 16/19) and 2014 (n = 16/19). These pregnancy rates suggest that the moose population in the study area is composed of reproductively healthy females with habitat, forage, and male ratios that support conception. Of the pregnant females in my study that were observed during calf surveys with single or twin calves, twinning rates were 66.7% in June 2013 (n = 6/9) and 45.5% in June 2014 (n = 5/11; Figure 3.8). These results represent a reproductively sustainable population that is perhaps increasing and currently below the carrying capacity of the area.

Adult female ungulates select parturition sites that balance the need to minimize predation risk and maximize access to high quality forage needed for the increased nutritional demands of lactation (Edwards 1983, Bowyer et al. 1999, Poole et al. 2007). In my study area, wetland and riparian habitat provides this balance of cover and forage. My study area is particularly unique in that it represents a southern range expansion, but also occurs in a highly fragmented landscape with 70% of the land cover being annual cropland (Agriculture and Agri-Food Canada 2013, 2014). Within the study area, there was only approximately 8.9% of wetland and riparian habitat available. However, female moose selected wetland and riparian buffer habitat as both parturition and post-parturition habitat. Selection ratios indicated that wetland and riparian habitat, trees and shrubs, and cropland were selected by female moose as parturition habitat, while pasture and forages, developed and native grassland habitat were avoided (Figure 3.9). During the 20 days post-parturition period, female moose selected for wetland and riparian areas, native grassland, cereal crops, and roads, while avoiding oilseed crops (Figure 3.8).

The results from the resource selection function indicate that only 10.2% of the area within the home ranges of parturient females is considered highly selected habitat with high probability of moose use, while 47.8% of the area has a low probability of habitat use by post-parturient moose (Figure 3.13 and 3.14). These results demonstrate the importance of existing semi-permanent and permanent wetlands within cropland to parturient female moose (Table 3.3, Figure 3.9).

4.5. Management Implications and Options

Understanding the home range size and habitat selection of parturient and post-parturient female moose with young provides a missing piece for the management of this newly established population. Moose management options will depend on society's desire to maintain a moose population in this agriculture dominated landscape and society's tolerance of moose-human conflicts, such as crop and tree damage, and moose-vehicle collisions (MVCs).

Wetland and riparian habitat including trees and shrubs are important to reproductive female moose in a landscape dominated by agriculture. Conservation and land management practices and policies will need to be revisited. Highly fragmented habitat, such as the wetlands surrounded by agricultural cropland in my study area, is often considered sink habitat surrounded by non-habitat (Herkert 1994, Donovan et al 1995). My research findings show that moose require wetlands and riparian habitat for successful reproduction during parturition and post-parturition. As such, these fragmented habitat patches (i.e., wetlands) surrounded by cropland have higher conservation value than originally thought. In order to maintain a healthy moose population with reproductive success semi-permanent and permanent wetlands with trees and shrubs should be conserved. New approaches to land management such as the Water Security Agency's *Saskatchewan Agricultural Water Management Strategy* should consider the value these wetlands have to wildlife (Water Security Agency 2019). Non-government organizations that focus on conservation through land management, such as the Nature Conservancy of Canada and Ducks Unlimited Canada, typically focus conservation efforts on intact and connected upland and wetland habitats. However, my research suggests that patches of wetland habitat are important to parturient and post-

parturient moose, therefore, these organizations should reconsider the conservation benefit of wetland habitat patches surrounded by cropland. With appropriate protection measures in place, these wetland patches of habitat could also contribute to the Canada Target 1 goal set out by the Canadian federal government in 2015 (Canadian Parks Council 2019). The Canada Target 1 goal is to have at least 17% of terrestrial areas and inland water, and 10% of marine and coastal areas of Canada conserved through networks of protected areas and other effective area-based measures by 2020 (Canadian Parks Council 2019). Effective conservation measures can include conservation easements, land ownership, or agreements that pay landowners for ecological goods and services. My results suggest that moose in this landscape likely benefit from habitat enhancement efforts already taking place, including the restoration of wetlands which is a focus of many Ducks Unlimited Canada projects (Ducks Unlimited Canada 2019).

Alternatively, wetland and riparian habitat surrounded by cropland can be perceived as an unnecessary attractant for moose that can increase the risk of human-moose conflicts, such as MVCs and crop damage. In a landscape where the risk of MVCs was previously very low, it may be desirable to strategically remove some of these small areas of habitat to reduce such risk. Habitat with its associated forage and cover is likely the main predictor for moose to use areas in proximity to transportation corridors (Hurley et al. 2007, Becker et al. 2011). Risk management for large ungulate collisions often includes increased hunting or culling, habitat management and fencing along roads, and supplemental feeding to attract wildlife to areas away from roads (Weisberg and Bugmann 2003). Removal of wetland and riparian habitat near roads or installing fence between roads and adjacent wetland habitat would reduce the risk of MVCs. Underpasses and overpasses for wildlife to cross major road corridors are used when areas with high wildlife crossings are known (McCollister and van Manen 2010). Underpasses and overpasses are major infrastructure projects and more information on MVCs would need to be collected prior to development. In addition to the management of moose populations and habitat manipulation near roads, changes in human driving behaviour (i.e., speeding, distracted driving, slowing down in low light conditions) are also necessary to reduce the risk of MVCs (Seiler 2003, Child 2007). Driver awareness of the risk of MVCs should be increased through road signage and media campaigns (Child 2007). The Saskatchewan Wildlife Federation (SWF) and Saskatchewan Government Insurance (SGI) have partnered on a driver awareness campaign called “Moose on the Loose” (Golden West Broadcasting 2019).

Landowners may choose to remove wetlands within their cropland, not only to increase productive acres, but also in an effort to reduce crop damage by wildlife that are attracted to these habitat patches. Laforge et al. (2016) suggests installing exclusion fencing around wetlands to prevent wildlife crop damage. However, this approach may prove ineffective as wildlife would move towards the wetland unaware that it is exclusion fenced and cause some level of crop damage regardless of whether they can access the wetland. Also, considerable investments in capital and time would be needed to install and maintain exclusion fencing around all wetlands surrounded by cropland (VerCauteren et al. 2006).

Anthropogenic-caused habitat loss and fragmentation is common throughout North America and has been identified as one of the primary drivers of declines and extinctions in mammal populations (Kosydar et al. 2014). After understanding the habitat requirements of reproductive moose in this expanding population, management options will depend on society's desire to maintain this moose population in this agriculture dominated landscape and ability to accept trade-offs between economic pressures and the natural environment. During a time when many other moose populations in North America are in serious decline, the expansion and persistence of this population serves as an important case study and focus of future research.

4.6. Literature Cited

Acton, D. F., G. A. Padbury, and C. T. Stushnoff. 1998. The Ecoregions of Saskatchewan. Saskatchewan Environment & Resource Management. Canadian Plains Research Centre. University of Regina, Regina, Saskatchewan.

Agriculture and Agri-Food Canada. 2013. Agriculture and Agri-Food Canada Annual Crop Inventory 2013.

Agriculture and Agri-Food Canada. 2014a. Agriculture and Agri-Food Canada Annual Crop Inventory 2014.

Agriculture and Agri-Food Canada. 2014b. ISO 19131 AAFC Annual Crop Inventory – Data Product Specifications.

Albright, C. A. and L. B. Keith. 1987. Population dynamics of moose, *Alces alces,* on the south-coast barrens of Newfoundland. Canadian Field-Naturalist 101:373–387.

Altmann, M. 1958. Social integrations of the moose calf. Animal Behaviour 6:155–159.

Altmann, M. 1963. Naturalistic studies of maternal care in moose and elk. Pages 233–253 *in* H. L. Rheingold, editor. Maternal behavior of mammals. J. Wiley, New York, New York, USA.

Alverson, W. S., D. M. Waller, and S. L. Solheim. 1988. Forests too deer: edge effects in northern Wisconsin. Conservation Biology 2:348-358.

Ando, A.W. and M. L. Mallory. 2012. Optimal portfolio design to reduce climate-related conservation uncertainty in the Prairie Pothole Region. Proceedings of the National Academy of Sciences of the United States of America 109:6484-6489.

Andreassen, H. P., H. Gundersen, and T. Storaas. 2005. The effect of scent-marking, forest clearing, and supplemental feeding on moose-train collisions. Journal of Wildlife Management 69:1125–1132.

Arnemo, J. M., T. J. Kreeger, and T. Soveri. 2003. Chemical immobilization of free-ranging moose. Alces 39:243–253.

Arsenault, A. A. 2000. Status and management of moose (*Alces alces*) in Saskatchewan. Saskatchewan Environment and Resource Management, Fish and Wildlife Branch. Technical Report 00-1.

Arsenault, A. A. 2008. Saskatchewan elk *(Cervus elaphus)* Management Plan – Update. Saskatchewan Ministry of Environment, Fish and Wildlife Branch Technical Report 2008–03.

Arsenault, A. A. 2009. Disturbance impact thresholds: recommended land use guidelines for protection of vertebrate species of concern in Saskatchewan. Saskatchewan Ministry of Environment, Lands Branch - Fish and Wildlife Branch Technical Report 2009-06.

Babcock, W. H., J.F. Kimball, J. A. Rensel, and M. L. Wolfe. 1982. Management alternatives for Utah moose. Alces 18:235-257.

Bahn, V. and B. J. McGill. 2013. Testing the predictive performance of distribution models. Oikos 122:321–331.

Ball, J. P., and J. Dahlgren. 2002. Browsing damage on pine (*Pinus sylvestris* and *P. contorta*) by a migrating moose (*Alces alces*) population in winter: relation to habitat composition and road barriers. Scandinavian Journal of Forest Research 17:427–435.

Ballard, W. B. and S. D. Miller. 1990. Effects of reducing brown bear density on moose calf survival in south-central Alaska. Alces 26:9–13.

Ballard, W. B., J. S. Whitman, and D. J. Reed. 1991. Population dynamics of moose in south-central Alaska. Wildlife Monographs 114.

Ballard, W. B. and V. Van Ballenberghe. 2007. Predator/Prey Relationships. Pages 223–273 *in* A.W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North America Moose. Second Edition. University Press of Colorado, Boulder, Colorado, USA.

Barbknecht, A. E., W. S. Fairbanks, J. D. Rogerson, E. J. Maichak, and L. L. Meadows. 2009. Effectiveness of vaginal-implant transmitters for locating elk parturition sites. Journal of Wildlife Management 73:144–148.

Barrett, M. W. 1972. A review of the diet, condition, diseases and parasites of the Cypress Hills moose. Proceedings of the North American Moose Conference and Workshop 8:60–79.

Bates, D., M. Mächler, B. M. Bolker, and S. C. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software 67:1–48.

Becker, S. A., R. M. Nielson, D. G. Brimeyer, and M. J. Kauffman. 2011. Spatial and temporal characteristics of moose highway crossings during winter in the Buffalo Fork Valley, Wyoming. Alces 47:69-81.

van Beest, F. M., L. E. Loe, A. Mysterud, and J. M. Milner. 2010. Comparative space use and habitat selection of moose around feeding stations. Journal of Wildlife Management 74:219–227.

van Beest, F. M., I. M. Rivrud, L. E. Loe, J. M. Milner, and A. Mysterud. 2011. What determines variation in home range size across spatiotemporal scales in a large browsing herbivore? Journal of Animal Ecology 80:771–785.

van Beest, F. M., and J. M. Milner. 2013. Behavioural responses to thermal conditions affect seasonal mass change in a heat-sensitive northern ungulate. PLoS ONE 8(6) e65972.

van Beest, F. M., E. Vander Wal, A. V. Stronen, P. C. Paquet, and R. K. Brook. 2013. Temporal variation in site fidelity: scale-dependent effects of forage abundance and predation risk in a non-migratory large herbivore. Oecologia 173:409–420.

van Beest, F. M., P. D. McLoughlin, E. Vander Wal, and R. K. Brook. 2014. Temporal variation in site fidelity: scale-dependent effects of forage abundance and predation risk in a non-migratory large herbivore. Oecologia 173:409–420.

Belovsky, G. 1978. Diet optimization in a generalist herbivore: the moose. Theoretical Population Biology 14:105–134.

Belyea, B. (editor). 2000. A Year Inland – the Journal of a Hudson's Bay Company Winterer. (Henday, Anthony, fl. 1748–1755). Wilfrid Laurier University Press. Waterloo, Ontario, Canada.

Benson, J. F. and B. R. Patterson. 2013. Moose (*Alces alces*) predation by eastern coyotes (*Canis latrans*) and eastern coyote × eastern wolf (*Canis latrans* × *Canis lycaon*) hybrids. Canadian Journal of Zoology 91:837–841.

Berg, W. E. and R. L. Phillips. 1974. Habitat use by moose in northwestern Minnesota with reference to other heavily willowed areas. Naturaliste Canadien 101:101–116.

Bergqvist, G., R. Bergström, and L. Edenius. 2003. Effects of moose (*Alces alces*) rebrowsing on damage development in young stands of Scots pine (*Pinus sylvestris*). Forest Ecology and Management 176:397–403.

Bergström, R., and K. Danell. 1987. Effects of simulated winter browsing by moose on morphology and biomass of two birch species. Journal of Ecology 75:533–544.

Beyer, H. L. 2012. Geospatial Modelling Environment Version 0.7.2 RC2. Spatial Ecology LLC. http://www.spatialecology.com/gme. Accessed 30 November 2019.

Beyer, H. L., R. Ung, D. L. Murray, and M.-J. Fortin. 2013. Functional responses, seasonal variation and thresholds in behavioural responses of moose to road density. Journal of Applied Ecology 50:286–294.

Bjørneraas, K., E. J. Solberg, I. Herfindal, B. Van Moorter, C. M. Rolandsen, J. Tremblay, C. Skarpe, B. Sæther, R. Eriksen, and R. Astrup. 2011. Moose *Alces alces* habitat use at multiple temporal scales in a human-altered landscape. Wildlife Biology 17:44–54.

Bjørneraas, K., B. Van Moorter, C. M. Rolandsen, and I. Herfindal. 2010. Screening global positioning system data for errors using animal movement characteristics. Journal of Wildlife Management 74:1361–1366.

Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. Geange, J. R. Poulsen, M. H. H. Stevens, and J. S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24:127–135.

Boer, A. H. 1992. Fecundity of North American Moose (*Alces alces*): A Review. Alces Supplement 1:1–10.

Boyce, M. S. and L. L. McDonald. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology & Evolution 14:268–272.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281–300.

Boyce, M. S. 2006. Scale for resource selection functions. Diversity and Distributions 12:269–276.

Bowyer, R. T., V. van Ballenberghe, J. G. Kie, and J. A. K. Maier. 1999. Birth-site selection by Alaskan moose: maternal strategies for coping with a risky environment. Journal of Mammalogy 80:1070–1083.

Briggs, J. M., A. K. Knapp, J. M. Blair, J. L. Heisler, G. A. Hoch, M. S. Lett, and J. K. McCarron. 2005. An ecosystem in transition: causes and consequences of the conversion of mesic grassland to shrubland. Bioscience 55:243–254.

British Columbia Ministry of Forests - Lands and Natural Resource Operations. 2014. Provincial overview of moose population estimates for 2014. Factsheet, June 17, 2014. http://www.env.gov.bc.ca/fw/wildlife/management-issues/docs/factsheet_provincial_moose_population_june2014.pdf. Accessed 6 April 2016.

Broders, H. G., A. B. Coombs, and J. R. McCarron. 2012. Ecothermic responses of moose (Alces alces) to thermoregulatory stress on mainland Nova Scotia. Alces 48:53–61.

Brook, R. 2009. Historical review of elk–agriculture conflicts in and around Riding Mountain National Park, Manitoba, Canada. Human–Wildlife Interactions 3:72–87.

Brook, R. K. 2010. Habitat selection by parturient elk (*Cervus elaphus*) in agricultural and forested landscapes. Canadian Journal of Zoology 88:968–976.

Brook, R., A. Wheeler, M. Laforge, and N. Michel. 2016. Habitat selection, home range, movements, and reproduction of adult female moose in the agricultural landscape of Saskatchewan. Final Technical Report. University of Saskatchewan.

Broughton, R. S. and P. J. Jutras. 2013. Farm Drainage. The Canadian Encyclopedia. https://www.thecanadianencyclopedia.ca/en/article/farm-drainage. Accessed 14 January 2020.

Brown, J. S. and M. L. Rozenweig. 1986. Habitat selection in slowly regenerating environments. Journal of Theoretical Biology 123:151–171.

Bryant, L. M. 2002. A Reanalysis of the Long Creek Site: 45 years after the Excavation. M.A. Thesis, Department of Anthropology and Archaeology. University of Saskatchewan, Saskatoon, Canada.

Bryant, J. P., and P. J. Kuropat. 1980. Selection of winter forage by subarctic browsing vertebrates: The role of plant chemistry. Annual Review of Ecology, Evolution, and Systematics 11:261–285.

Bubenik, A. B. 2007. Evolution, Taxonomy, and Morphophysiology. Pages 77-123 *in* A.W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North America Moose. Second Edition. University Press of Colorado, Boulder, Colorado, USA.

Burcham, M., W. D. Edge, and C. L. Marcum. 1999. Elk use of private land refuges. Wildlife Society Bulletin 27:833–839.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practice Information-Theoretical Approach. Second Edition. Springer, New York, New York, USA.

Byers, C. R., R. K. Steinhorst, and R. R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. Journal of Wildlife Management 48: 1050–1053.

Calenge, C. 2006. The package "adehabitat" for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516–519.

Canadian Parks Council. 2019. Pathway to Canada Target 1. https://www.conservation2020canada.ca/the-pathway. Accessed 29 November 2019.

Capellini, I., J. Baker, W. L. Allen, S. E. Street, and C. Venditti. 2015. The role of life history traits in mammalian invasion success. Ecology Letters 18:1099-1107.

Carpenter, L. H., and J. I. Innes. 1995. Helicopter netgunning: a successful moose capture technique. Alces 31:181–184.

Cederlund, G. N., F. Sandegren, and K. Larsson. 1987. Summer movements of female moose and dispersal of their offspring. Journal of Wildlife Management 51:342–352.

Cederlund, G. N. and H. Okarma. 1988. Home range and habitat use of adult female moose. Journal of Wildlife Management 52:336–343.

Chamberlin, T.C. 1965. The Method of Multiple Working Hypotheses. Science 148:754–759.

Cheaib, A., V. Badeau, J. Boe, I. Chuine, C. Delire, E. Dufrêne, C. François, E. S. Gritti, M. Legay, C. Pagé, W. Thuiller, N. Viovy, and P. Leadley. 2012. Climate change impacts on

tree ranges: model intercomparison facilitates understanding and quantification of uncertainty. Ecology Letters 15:533-544.

Chetkiewicz, C.-L. B., and M. S. Boyce. 2009. Use of resource selection functions to identify conservation corridors. Journal of Applied Ecology 46:1036–1047.

Child, K. N. 2007. Incidental Mortality. Pages 275–301 *in* A.W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North America Moose. Second Edition. University Press of Colorado, Boulder, Colorado, USA.

Ciuti, S, P. Bongi, S. Vassale, and M. Apollonio. 2006. Influence of fawning on the spatial behaviour and habitat selection of female fallow deer (*Dama dama*) during late pregnancy and early lactation. Journal of Zoology 268:97–107.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2012. COSEWIC assessment and status report on the Grizzly Bear *Ursus arctos* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiv + 84 pp. http://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_ours_grizz_bear_1012_e.pdf Accessed 12 July 2018.

Conover, M. R. 1997. Monetary and intangible valuation of deer in the United States. Wildlife Society Bulletin 25:298-305.

Corlatti, L., K. Hackländer, and F. Frey-Roos. 2009. Ability of wildlife overpasses to provide connectivity and prevent genetic isolation. Conservation Biology 23:548–556.

Côté, S. D., T. P. Rooney, J.-P. Tremblay, C. Dussault, and D. M. Waller. 2004. Ecological impacts of deer overabundance. Annual Review of Ecology, Evolution, and Systematics 35:113–147.

Courtois, R., C. Dussault, F. Potvin, and G. Daigle. 2002. Habitat selection by moose (*Alces alces*) in clear-cut landscapes. Alces 38:177–192.

Crossley, A., and J. R. Gilbert. 1983. Home range and habitat use of moose in northern Maine: a preliminary look. Transactions of the Northeast Section of the Wildlife Society 40:67–75.

Cushman, S. A., M. Chase, and C. Griffin. 2005. Elephants in space and time. Oikos 109:331–341.

Cushman, S. A. 2010. Animal Movement Data: GPS Telemetry, Autocorrelation, and the Need for Path-Level Analysis. Pages 131–149 *in* S. A. Cushman and F. Huettmann, editors.

Spatial Complexity, Informatics, and Wildlife Conservation. Springer Science & Business Media.

Danell, K., L. Edenius, and P. Lundberg. 1991a. Herbivory and tree stand composition: moose patch size in winter. Ecology 72:1350–1357.

Danell, K., P. Niemelå, T. Varvikko, and T. Vuorisalo. 1991b. Moose browsing on Scots pine along a gradient of plant productivity. Ecology 72:1624–1633.

Darimont, C. T., P. C. Paquet, T. E. Reimchen, and V. Crichton. 2005. Range expansion by moose into coastal temperate rainforests of British Columbia, Canada. Diversity and Distributions 11:235-239.

Dawe, K. L. 2011. Factors driving range expansion of white-tailed deer, *Odocoileus virginianus*, in the boreal forest of northern Alberta, Canada. Dissertation, University of Alberta.

DeCesare, N. J., T. D. Smucker, R. A. Garrott, and J. A. Gude. 2014. Moose status and management in Montana. Alces 50:35–51.

DelGiudice, G. D., W. J. Severud, T. R. Obermoller, R. G. Wright, T. A. Enright, and V. St-Louis. 2015. Monitoring movement behavior enhances recognition and understanding of capture-induced abandonment of moose neonates. Journal of Mammalogy 96:1005–1016.

DeMars, C. A., M. Auger-Méthé, U. E. Schlägel, and S. Boutin. 2013. Inferring parturition and neonate survival from movement patterns of female ungulates: a case study using woodland caribou. Ecology and Evolution 3:4149–4160.

Desmarais, S., K. Miler, and H. Jacobson. 2000. White-tailed deer. Pages 601–628 *in* D. Desmarais and P.R. Krausman, editors. Ecology and Management of Large Mammals in North America. Prentice-Hall Inc., New Jersey.

Dettki, H., R. Löfstrand, and L. Edenius. 2003. Modeling habitat suitability for moose in coastal Northern Sweden: empirical vs process-oriented approaches. Ambio 32:549–556.

Dettki, H., G. Ericsson, and L. Edenius. 2004. Real-time moose tracking: an internet based mapping application using GPS/GSM-collars in Sweden. Alces 40:13–21.

Dochtermann, N. A., and S. H. Jenkins. 2011. Developing multiple hypotheses in behavioral ecology. Behavioral Ecology and Sociobiology 65:37–45.

Dodds, D. G. 1955. A contribution to the ecology of the moose in Newfoundland. M.Sc. Thesis. Cornell University, New York, New York, USA.

Donovan, T. M., F. R. Thompson, III, J. Faaborg, and J. R. Probst. 1995. Reproductive success of migratory birds in habitat sources and sinks. Conservation Biology 9:1380–1395.

Dorn, R. D. 1970. Moose and cattle food habits in southwest Montana. Journal of Wildlife Management 34:559–564.

Dormann, C. F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J. R., G. Marquéz, B. Gruber, B. Lafourcade, P. J. Leitão, T. Münkemüller, C. McClean, P. E. Osborne, B. Reineking, B. Schröder, A. K. Skidmore, D. Zurell, and S. Lautenbach. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36:27–46.

Ducks Unlimited Canada. 2019. Our Work / Approach: Landowners. https://www.ducks.ca/our-work/landowners/. Accessed 30 November 2019.

Duquette, J. F., J. L. Belant, N. J. Svoboda, D. E. Beyer Jr, and P. E. Lederle. 2014. Effects of maternal nutrition, resource use and multi-predator risk on neonatal white-tailed deer survival. PLOS One 9:1–10.

Dussault, C. J.-P. Ouellet, R. Courtois, J. Huot, L. Breton and J. Larochelle. 2004. Behavioural responses of moose to thermal conditions in the boreal forest. Écoscience 11:321–328.

Dussault, C., J.-P. Ouellet, R. Courtois, J. Huot, L. Breton, and H. Jolicoeur. 2005a. Linking moose habitat selection to limiting factors. Ecography 28:619–628.

Dussault, C., R. Courtois, J.-P. Ouellet, and I. Girard. 2005b. Space use of moose in relation to food availability. Canadian Journal of Zoology 83:1431–1437.

Dussault, C., R. Courtois, and J.-P. Ouellet. 2006. A habitat suitability index model to assess moose habitat selection at multiple spatial scales. Canadian Journal of Forestry Resources 36:1097–1107.

Dussault, C., J.-P. Ouellet, C. Laurian, R. Courtois, M. Poulin, and L. Breton. 2007. Moose movement rates along highways and crossing probability models. Journal of Wildlife Management 71:2338–2345.

Dyck, I. G. 1970. Two Oxbow Settlement Types in Central Saskatchewan. NAPAO – A Saskatchewan Anthropology Journal Volume 2 No. 2. October 1970.

Dybas, C. L. 2009. Minnesota's Moose: Ghosts of the Northern Forest? BioScience 59:824-828.

Dyck, I. G. and R. E. Morlan. 1995. The Sjovold Site: A River Crossing Campsite in the Northern Plains. Contributions by E. A. Christiansen, H. E. Hendry, D. W. Anderson and

J. G. Ellis. Mercury Series Archaeological Survey of Canada Paper 151, Canadian Museum of Civilization, Hall, Quebec, Canada.

Edenius, L., K. Danell, and R. Bergström. 1993. Impact of herbivory and competition on compensatory growth in woody plants: winter browsing by moose on Scots pine. Oikos 66:286–292.

Edwards, J. 1983. Diet shifts in moose due to predator avoidance. Oecologia 60:185–189.

Edwards, R. Y. and R. W. Ritcey. 1958. Reproduction in a moose population. Journal of Wildlife Management 22:261–268.

Ehrlich, P. R. 1988. The loss of diversity causes and consequences. Pages 21-27 *in* E.O. Wilson, editor. Biodiversity. National Academy Press, Washington, DC, USA.

Elliott, L. P. and B. W. Brook. 2007. Revisiting Chamberlin: Multiple working hypotheses for the 21st Century. BioScience 57:606–614.

Ellis, J. E., J. A. Wiens, C. F. Rodell, and J. C. Anway. 1976. A conceptual model of diet selection as an ecosystem process. Journal of Theoretical Biology 60:93–108.

Enserink, M. and G. Vogel. 2006. The carnivore comeback. Science 314:746–749.

Environmental Systems Research Institute (ESRI). 2014. ArcGIS 10.2.1. Redlands, CA

Epps, C. W., P. J. Palsbøll, J. D. Wehausen, G. K. Roderick, R. R. Ramey II, and D. R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters 8:1029–1038.

Fagerstone, K., and W. Clay. 1997. Overview of USDA animal damage control efforts to manage overabundant deer. Wildlife Society bulletin 25:413–417.

Ferguson, S. H., A. T. Bergerud, and R. Ferguson. 1988. Predation risk and habitat selection in the persistence of a remnant caribou population. Oecologia 76:236–245.

Fieberg, J., J. Matthiopoulos, M. Hebblewhite, M. S. Boyce, and J. L. Frair. 2010. Correlation and studies of habitat selection: problem, red herring or opportunity?

Fraser, H. and R. Fleming. 2001. Environmental Benefits of Tile Drainage - Literature Review. Prepared for: LICO - Land Improvement Contractors of Ontario. University of Guelph. https://www.ridgetownc.com/research/documents/fleming_drainage.pdf. Accessed 14 January 2020.

Fretwell, S. D. and H. L. Lucas Jr. 1969. On territorial behavior and other factors influencing habitat distribution in birds. Acta Biotheoretica 14:16–36.

Fortin, D., D. W. Morris, and P. D. McLoughlin. 2008. Habitat selection and the evolution of specialists in heterogeneous environments. Israel Journal of Ecology & Evolution 54:311–328.

Fortin, D., H. L. Beyer, M. S. Boyce, D. W. Smith, T. Duchesne, and J. S. Mao. 2005. Wolves influence elk movements: behavior shapes a trophic cascade in Yellowstone National Park. Ecology 86:1320–1330.

Fortin, M-J. and M. R. T. Dale. 2005. Spatial analysis: a guide for ecologists. Cambridge University Press, New York, USA.

Franzmann, A.W. and C. C. Schwartz. 1985. Moose twinning rates: a possible population condition assessment. Journal of Wildlife Management 49:394–396.

Franzmann, A.W., C. C. Schwartz, and R. O. Peterson. 1980. Moose calf mortality in summer on the Kenai Peninsula, Alaska. Journal of Wildlife Management 44:764–768.

Gaillard, J.-M. 2007. Are moose only a large deer? Some life history considerations. Alces 43:1–11.

Garner, D. L. and W. F. Porter. 1990. Movements and seasonal home ranges of bull moose in a pioneering Adirondack population. Alces 26:80–85.

Gasaway, W. C., S. D. Dubois, and K. L. Brink. 1980. Dispersal of subadult moose from a low density population in interior Alaska. Proceedings of the North American Moose Conference and Workshop No. 16:314–337.

Gasaway, W. C., R. D. Boerje, D. V. Grandgard, K. G. Kellyhouse, R. O. Stephenson, and D. G. Larsen. 1992. The role of predation in limiting moose at low densities in Alaska and Yukon and implications for conservation. Wildlife Monographs 120.

Geist, V. 1963. On the behaviour of the North American Moose (*Alces alces andersoni* Peterson 1950) in British Columbia. Behaviour 20:377–416.

Geist, V. 1971. Mountain sheep: a study in behaviour and evolution. University of Chicago Press, Chicago, Illinois, USA.

Geist, V. 1974. On the relationship of social evolution and ecology in ungulates. American Zoologist 14:205-220.

Gillies, C. S., M. Hebblewhite, S. E. Nielsen, M. A. Krawchuk, C. L. Aldridge, J. L. Frair, D. J. Saher, C. E. Stevens, and C. L. Jerde. 2006. Application of random effects to the study of resource selection by animals. Journal of Animal Ecology 75:887–898.

Global Positioning Solutions Inc. 2013. President: W. Voth. Winnipeg, Manitoba, Canada.

Goetz S. J., A. G. Bunn, G. J. Fiske, and R. A. Houghton. 2005. Satellite-observed photosynthetic trends across boreal North America associated with climate and fire disturbance. In: Proceedings of the National Academy of Sciences of the United States of America 102:13521–13525.

Golden West broadcasting. 2019. Discover Moose Jaw: Moose On The Loose. Published 06 July 2011. https://www.discovermoosejaw.com/local/moose-on-the-loose-1. Accessed 30 November 2019.

Government of Canada. 2014. Climate: Canadian Climate Normals - 1981–2010 Climate Normals & Averages. http://climate.weather.gc.ca/climate_normals/index_e.html. Accessed 18 November 2014.

Government of Canada. 2016. Climate: Monthly Climate Summaries by Station Name. http://climate.weather.gc.ca/advanceSearch/searchHistoricData_e.html. Accessed 20 December 2016.

Government of Saskatchewan. 2014. Saskatchewan Hunters' and Trappers' Guide 2014. http://www.environment.gov.sk.ca/Default.aspx?DN=2a5dfe9f-6442-4667-ad59-253883e8b8e2. Accessed 18 November 2014.

Government of Saskatchewan. 2018a. 2018 Saskatchewan Resident Big Game Draw Supplement. http://publications.gov.sk.ca/documents/66/76502-2018%20Big%20Game%20Draw%20Supplement.pdf. Accessed 11 July 2018.

Government of Saskatchewan. 2018b. Saskatchewan Hunters' and Trappers' Guide 2018. http://publications.gov.sk.ca/documents/66/93283-2018%20Hunters%20and%20Trappers%20Guide.pdf. Accessed 11 July 2018.

Government of Saskatchewan. 2019a. Saskatchewan Hunters' and Trappers' Guide 2019. https://pubsaskdev.blob.core.windows.net/pubsask-prod/93283/2019%252BHunters%252Band%252BTrappers%252BGuide.pdf. Accessed 29 November 2019.

Government of Saskatchewan. 2019b. 2019 Saskatchewan Resident Big Game Draw Supplement. https://pubsaskdev.blob.core.windows.net/pubsask-prod/76502/2019%252BBig%252BGame%252BDraw%252BSupplement.pdf. Accessed 30 November 2019.

Graves, T. A. and J. S. Walker. 2006. Understanding the causes of missed global positioning system telemetry fixes. Journal of Wildlife Management 70:844–851.

Guisan, A., T. C. Edwards, Jr., and T. Hastie. 2002. Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecological Modeling 157:89-100.

Haigh, J. C., E. H. Kowal, W. Runge, G. Wobeser. 1982. Pregnancy diagnosis as a management tool for moose. Alces 18:45–53.

Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. Wildlife Society Bulletin 25:173–182.

Halls, L. K., R. E. McCabe, and L. R. Jahn. 1984. White-tailed deer: ecology and management. Stackpole Books, Harrisburg, Pennsylvania.

Hamilton, G. D., P. D. Drysdale, and D. L. Euler. 1980. Moose winter browsing patterns on clear-cuttings in northern Ontario. Canadian Journal of Zoology 58:1412–1416.

Hammermeister, A.M., D. Gauthier, and K. McGovern. 2001. Saskatchewan's Native Prairie: Statistics of a Vanishing Ecosystem and Dwindling Resource. Native Plant Society of Saskatchewan Inc., Saskatoon, Saskatchewan.

Harris, S., W.J. Cresswell, P.G. Forde, W.J. Trewhella, T. Woolard, and S. Wray. 1990. Home-range analysis using radio-tracking data—a review of problems and techniques particularly as applied to the study of mammals. Mammalian Rev. 20:97–123.

Hauge, T. M. and L. B. Keith. 1981. Dynamics of moose populations in north eastern Alberta. Journal of Wildlife Management 45:573–597.

Heard, D., S. Barry, G. Watts, and K. Child. 1997. Fertility of female moose (*Alces alces*) in relation to age and body composition. Alces 33:165–176.

Hebblewhite, M., and E. Merrill. 2008. Modelling wildlife-human relationships for social species with mixed-effects resource selection models. Journal of Applied Ecology 45:834–844.

Heikkilä, R., and S. Härkönen. 1996. Moose browsing in young Scots pine stands in relation to forest management. Forest Ecology and Management 88:179–186.

Hemson, G., P. Johnson, A. South, R. Kenward, R. Ripley, and D. McDonald. 2005. Are kernels the mustard? Data from Global Positioning System (GPS) collars suggests problems for kernel home-range analyses with least-squares cross-validation. Journal of Animal Ecology 74:455–463.

Herkert, J. R. 1994. The effects of habitat fragmentation on Midwestern grassland bird communities. Ecological Applications 4:461–471.

Hobbs, N. T. 2003. Challenges and opportunities in integrating ecological knowledge across scales. Forest Ecology and Management 181:223–238.

Hochachka, W. M., R. Caruana, D. Fink, A. Munson, M. Riedewald, D. Sorokina, and S. Kelling. 2007. Data-mining discovery of pattern and process in ecological systems. Journal of Wildlife Management 71:2427–2437.

Holderegger, R., and M. Di Giulio. 2010. The genetic effects of roads: A review of empirical evidence. Basic and Applied Ecology 8:1029–1038.

Hurley, M. V., E. K. Rapaport, and C. J. Johnson. 2007. A spatial analysis of moose-vehicle collisions in Mount Revelstoke and Glacier National Parks, Canada. Alces 43: 79–100.

Hundertmark, K. J. 2007. Home range, dispersal and migration. Pages 303–335 *in* A.W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North America Moose. Second Edition. University Press of Colorado, Boulder, Colorado, USA.

Irby, L. R., W. E. Zidack, J. B. Johnson, and J. Saltiel. 1996. Economic damage to forage crops by native ungulates as perceived by farmers and ranchers in Montana. Journal of Range Management 49:375–380.

Isaac, V. and W. A. van Wijngaarden, 2012. Surface Water Vapor Pressure and Temperature Trends in North America during 1948–2010. Journal of Climate 25:3599-3609.

Jackson, R. M., M. White, and F. F. Knowlton. 1972. Activity patterns of white-tailed deer fawns in south Texas. Ecology 53:262–270.

Jiang, Z., M. Sugita, M. Kitahara, S. Takatsuki, T. Goto, Y. Yoshida. 2008. Effects of habitat feature, antenna position, movement, and fix interval on GPS radio collar performance in Mount Fuji, central Japan. Ecological Research 23:581–588.

Johnson, C. J., S. E. Nielsen, E. H. Merril, T. L. McDonald, and M. S. Boyce. 2006. Resource selection functions based on use-availability data: theoretical motivation and evaluation methods. Journal of Wildlife Management 70:347–357.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Johnson, J. B., and K. S. Omland. 2004. Model selection in ecology and evolution. Trends in Ecology & Evolution 19:101–108.

Joyce, T. L., and S. P. Mahoney. 2001. Spatial and temporal distribution of moose-vehicle collisions in Newfoundland. Wildlife Society Bulletin 29:281-291.

Jung, T. S., T. E. Chubbs, C. G. Jones, F. R. Phillips, and R. D. Otto. 2009. Winter habitat associations of a low-density moose (*Alces americanus*) population in central Labrador. Northeastern Naturalist 16:471–480.

Karns, P. D. 2007. Population distribution, density, and trends. Pages 125–140 *in* A.W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North America Moose. Second Edition. University Press of Colorado, Boulder, Colorado, USA.

Keech, M. A., R. D. Boertje, R. Terry Bowyer, and B. W. Dale. 1999. Effects of birth weight on growth of young moose: do low-weight neonates compensate. Alces 35:51–57.

Keech, M. A., M. S. Lindberg, R. D. Boertje, P. Valkenburg, B. D. Taras, T. A. Boudreau, and K. B. Beckmen. 2011. Effects of predator treatments, individual traits, and environment on moose survival in Alaska. Journal of Wildlife Management 75:1361–1380.

Kelsall, J. P. 1972. The northern limits of moose (*Alces alces*) in Western Canada. Journal of Mammalogy: 53:129-138.

Kelsall, J. P., and E. S. Telfer. 1974. Biogeography of moose with particular reference to western North America. Naturaliste Canadien 101:117-130.

Kelsall, J. P., E. S. Telfer, and T. D. Wright. 1977. The effects of fire on the ecology of the boreal forest, with particular reference to the Canadian north: a review and selected bibliography. Occasional Paper No. 323. Canadian Wildlife Service, Ottawa, Ontario, Canada.

Knopff, K. H., A. A. Knopff, A. Kortello, and M. S. Boyce. 2010. Cougar kill rate and prey composition in a multiprey system. Journal of Wildlife Management 74:1435–1447.

Kosydar, A. J., L. L. Conquest, and J. J. Tewksbury. 2014. Can life histories predict the effects of habitat fragmentation? A meta-analysis with terrestrial mammals. Applied Ecology and Environmental Research 12:505-521.

Kotchorek, R. E. 2002. Response of moose calf survival to reduced black bear density: An assessment of the stresses likely affecting the moose population on Hecla Island. M.Sc. Thesis, Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada.

Kreeger, T. J. 2000. Xylazine-induced aspiration pneumonia in Shiras moose. Wildlife Society Bulletin 28: 751–753.

Kunkel, K. E. and D. H. Pletscher. 2000. Habitat factors affecting vulnerability of moose to predation by wolves in southeastern British Columbia. Canadian Journal of Zoology 78:150–157.

Labonté, J., J.-P. Ouellet, R. Courtois, and F. Belisle. 1998. Moose dispersal and its role in the maintenance of harvested populations. Journal of Wildlife Management 62:225–235.

Laforge, M. P., R. K. Brook, F. M. van Beest, E. M. Bayne, and P. D. McLoughlin. 2015. Grain-dependent functional responses in habitat selection. Landscape Ecology DOI 10.1007/s10980-015-0298-x

Laforge, M. P., N. L. Michel, A. L. Wheeler, and R. K. Brook. 2016. Habitat selection by female moose in the Canadian Prairie Ecozone. Journal of Wildlife Management 80:1059–1068.

Laforge, M. P., N. L. Michel, and R. K. Brook. 2017. Spatio-temporal trends in crop damage inform recent climate mediated expansion of a large boreal herbivore into an agroecosystem. Scientific Reports 7, Article No. 15203 (2017).

Legendre, P. 1993. Spatial Autocorrelation: Trouble or New Paradigm? Ecology 74:1659–1673.

Legendre, P. and M-J. Fortin. 1989. Spatial pattern and ecological analysis. Vegetatio 80:107–138.

Lenarz, M. S., M. E. Nelson, M. W. Schrage, and A. J. Edwards. 2009. Temperature mediated moose survival in Northeastern Minnesota. Journal of Wildlife Management 73:503-510.

Lenarz, M. S., R. G. Wright, M. W. Schrage, and A. J. Edwards. 2011. Compositional analysis of moose habitat in Northeastern Minnesota. Alces 47:135–149.

Lent, P. C. 1974. Mother infant relationships in ungulates. Pages 14–55 *in* V. Geist and F. Walther, editors. The behaviour of ungulates and its relation to management. Volumes I and II. International Union for the Conservation of Nature, Morges, Switzerland.

Leptich, D. J., and J. R. Gilbert. 1989. Summer home range and habitat use by moose in northern Maine. Journal of Wildlife Management 53:880–885.

LeResche, R. E. 1968. Spring-fall calf mortality in an Alaska moose population. Journal of Wildlife Management 32:953–956.

LeResche, R. E. and J. L. Davis. 1973. Importance of nonbrowse foods to moose on the Kenai Peninsula, Alaska. Journal of Wildlife Management 37:279–287.

Lewis, J. S., J. L. Rachlow, E. O. Garton, and L. A. Vierling. 2007. Effects of habitat on GPS collar performance: using data screening to reduce location error. Journal of Applied Ecology 44:663–671.

Long, R. A., J. G. Kie, R. T. Bowyer, and M. A. Hurley. 2009. Resource selection and movements by female mule deer *Odocoileus hemionus*: effects of reproductive stage. Wildlife Biology 15:288–298.

Lowe, S. J., B. R. Patterson, and J. A. Schaefer. 2010. Lack of behavioral responses of moose (*Alces alces*) to high ambient temperatures near the southern periphery of their range. Canadian Journal of Zoology 88:1032–1041.

Lykkja, O. N., E. J. Solberg, I. Herfindal, J. Wright, C. M. Rolandsen, and M. G. Hanssen. 2009. The effects of human activity on summer habitat use by moose. Alces 45: 109–124.

Main, M. B. 2008. Reconciling competing ecological explanations for sexual segregation in ungulates. Ecology 89:693–704.

Mandelbaum, D. G. 1979. The Plains Cree: An Ethnographic, Historical, and Comparative Study. Canadian Plains Studies 9, Canadian Plains Research Center, University of Regina, Regina, Saskatchewan, Canada.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald and W. P. Erickson. 2002. Resource selection by animals: statistical analysis and design for field studies. Second Edition. Kluwer, Boston, USA.

Månsson, J., R. Bergstrom, and K. Danell. 2009. Fertilization-Effects on deciduous tree growth and browsing by moose. Forest Ecology and Management 258:2450–2455.

Månsson, J., H. Andrén, Å. Pehrson, and R. Bergstrom. 2007. Moose browsing and forage availability: a scale-dependent relationship? Canadian Journal of Zoology 85:372–380.

Mao, J. S., M. S. Boyce, D. W. Smith, F. J. Singer, D. J. Vales, J. M. Vore, E. H. Merrill. 2005. Habitat selection by elk before and after wolf reintroduction in Yellowstone National Park. Journal of Wildlife Management 69:1691–1707.

McCabe, R. E., and T. R. McCabe. 1984. Of slings and arrows: an historical retrospection. Pages 19-72 *in* L. K. Halls, editor. White-Tailed Deer: Ecology and Management. Stackpole Books, Harrisburg, PA, USA.

McCollister, M. F. and F. T. van Manen. 2010. Effectiveness of wildlife underpasses and fencing to reduce wildlife–vehicle collisions. Journal of Wildlife Management 74:1722–1732.

McGraw, A. M. 2011. Characteristics of post-parturition areas of moose and effective temperature of cover types in moose home ranges in northeast Minnesota. M.Sc. Thesis, University of Minnesota, Duluth, Minnesota, USA.

McLaren, A. A. D., J. F. Benson, and B. R. Patterson. 2017. Multiscale habitat selection by cow moose (*Alces Alces*) at calving sites in central Ontario. Canadian Journal of Zoology 95:891–899.

McLoughlin P. D., M. S. Boyce, T. Coulson, and T. Clutton-Brock. 2006. Lifetime reproductive success and density-dependent, multi-variable resource selection. Proceedings of the Royal Society B: Biological Sciences 273:1449–1454.

Mech, L. D. 1970. The wolf: ecology and behavior of an endangered species. Natural History Press, Garden City, New York, New York, USA.

Mech, L. D. 1977. Wolf-pack buffer zones as prey reservoirs. Science 198:320–321.

Melin, M., J. Matala, L. Mehtätalo, R. Tiilikainen, O.-P. Tikkanen, M. Maltamo, J. Pusenius, and P. Packalen. 2014. Moose (*Alces alces*) reacts to high summer temperatures by utilizing thermal shelters in boreal forests – an analysis based on airborne laser scanning of the canopy structure at moose locations. Global Change Biology 20:1115–1125.

Milner, J. M., A. Stien, R. J. Irvine, S. D. Albon, R. Langvatn, and E. Ropstad. 2003. Body condition in Svalbard reindeer and the use of blood parameters as indicators of condition and fitness. Canadian Journal of Zoology 81:1566–1578.

Milner, J. M., F. M. van Beest, E. J. Solberg, and T. Storaas. 2013. Reproductive success and failure: the role of winter body mass in reproductive allocation in Norwegian moose. Oecologia 172:995–1005.

Minnesota Department of Agriculture. 2019. Minnesota Agricultural Profile. https://www.mda.state.mn.us/sites/default/files/inline-files/mnagprofile2019.pdf. Accessed 29 November 2019.

Minnesota Department of Natural Resources. 2016. Research begins to unravel mystery of moose deaths. http://www.dnr.state.mn.us/moose/index.html. Accessed 6 April 2016.

Montgomery, R. A., J. A. Vucetich, R. O. Peterson, G. J. Roloff, and K. F. Millenbah. 2013. The influence of winter severity, predation and senescence on moose habitat uses. Journal of Animal Ecology 82:301–309.

Moreno, J. 2010. Reproductive Success. Pages 64–69 *in* M. D. Breed and J. Moore, editors. Encyclopedia of Animal Behavior. Vol. 3. Academia Press, Cambridge Massachusetts, USA.

Morris, P. A. 1988. A study of home range and movements in the hedgehog (*Erinaceus europaeus*). Journal of Zoology 214:433–449.

Morse, S. C. 2015. Declining Moose Populations: What Does the Future Hold? Northern Woodlands: Spring 2015. http://northernwoodlands.org/articles/article/moose-decline. Accessed 6 April 2016.

Muhly, T. B., C. Semeniuk, A. Massolo, L. Hickman, and M. Musiani. 2011. Human activity helps prey win the predator-prey space race. PLoS One 6: e17050. DOI: 10.1371/journal.pone.0017050

Murray, D. L., E. W. Cox, W. B. Ballard, H. A. Whitlaw, M. S. Lenarz, T. W. Custer, T. Barnett, and T. K. Fuller. 2006. Pathogens, nutritional deficiency, and climate influences on a declining moose population. Wildlife Monographs 166:1-30.

Musante, A. R., P. J. Pekins, and D. L. Scarpitti. 2010. Characteristics and dynamics of a regional moose *Alces alces* population in the northeastern United States. Wildlife Biology 16:185–204.

Mytton, W. R. and L. B. Keith. 1981. Dynamics of moose population near Rochester, Alberta, 1975–1978. Canadian Field-Naturalist 95:39–49.

Nagy, J. A. S. 2011. Use of space by caribou in northern Canada. PhD thesis, University of Alberta, Edmonton, Alberta, Canada.

National Agricultural Statistics Service. 2018. Montana Agricultural Facts 2017. https://www.nass.usda.gov/Statistics_by_State/Montana/Publications/Special_Interest_Reports/agfacts.pdf. Accessed 10 July 2018.

Navarro, L. M. and H. M. Pereira. 2012. Rewilding abandoned landscapes in Europe. Ecosystems 15:900–912.

Neumann, W., G. Ericsson, and H. Dettki. 2009. The non-impact of hunting on moose *Alces alces* movement, diurnal activity, and activity range. European Journal of Wildlife Research 55:255–265.

Neumann, W., G. Ericsson, and H. Dettki. 2011. The impact of human recreational activities: moose as a case study. Alces 47:17–25.

Nikula, A., S. Heikkinen, and E. Helle. 2004. Habitat selection of adult moose *Alces alces* at two spatial scales in central Finland. Wildlife Biology 10:121–135.

Nixon, C. M., L. P. Hansen, P. A. Brewer, and J. E. Chelsvig. 1991. Ecology of white-tailed deer in an intensively farmed region of Illinois. Wildlife Monographs 118:3–77.

North American Bird Conservation Initiative. 2016. Bird Conservation Region 11 – Prairie Potholes. http://www.nabci-us.org/bcr11.html. Accessed 6 April 2016.

Nowlin, R. A. 1978. Habitat selection and food habits of moose in northeastern Alberta. Proceedings of the North American Moose Conference and Workshop No. 14:178–193.

Novecosky, A. A. 2003. The Heron Collection: Antelope Creek and Miry Creek sites, southwestern Saskatchewan. M.A. Thesis, Department of Anthropology and Archaeology. University of Saskatchewan, Saskatoon, Canada.

Odum, E. P. 1983. Fundamentals of Ecology. Third Edition. CBS College Publishing, New York, New York, USA.

Ohrens, O., A. Treves, and C. Bonacic. 2016. Relationship between rural depopulation and puma-human conflict in the high Andes of Chile. Environmental Conservation 43:24–33.

Ohring, G., P. Romanov, R. Ferraro, A. Heidinger, I. Laszlo, C.-Z. Zou, and M. Foster. 2014. Satellite Observations of North American Climate Change. Pages 95-166 *in* G. Ohring, editor. Climate Change in North America, Regional Climate Studies, Springer International Publishing, Switzerland.

Ontario Ministry of Natural Resources and Forestry. 2016. Moose population management. https://www.ontario.ca/page/moose-population-management. Accessed 6 April 2016.

Opdam, P., and D. Wascher. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117:285–297.

Parker, G. 2003. Status report on the eastern moose (*Alces alces americana* Clinton) in mainland Nova Scotia. Retrieved April 7, 2016. https://www.novascotia.ca/natr/wildlife/large-mammals/pdf/StatusReportMooseNS.pdf

Parker, K. L., and M. P. Gillingham. 2007. Habitat use and selection by moose and elk in the Besa-Prophet. Part 4 of Project: An Ecosystem Approach to Habitat Capability Modelling and Cumulative Effects Management. Prepared for: Muskwa-Kechika Advisory Board. Natural Resources and Environmental Studies, University of Northern British Columbia.

Patterson, B. R., J. F., Benson, K. R., Middel, K. J. Mills, A. Silver, and M. E. Obbard. 2013. Moose calf mortality in central Ontario, Canada. Journal of Wildlife Management 77:832–841.

Peek, J. M. 1974. A review of moose food habits studies in North America. Naturaliste Canadien 101:195–215.

Peek, J. M., D. L. Urich, and R. J. Mackie. 1976. Moose habitat selection and relationships to forest management in Northeastern Minnesota. Wildlife Monographs 48:3–65.

Peek, J. M. 2007. Habitat relationships. Pages 351–375 *in* A.W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North America Moose. Second Edition. University Press of Colorado, Boulder, Colorado, USA.

Peterson, R. L. 1955. North American Moose. University of Toronto Press, Toronto, Ontario, Canada.

Peterson, R. L. 1977. Wolf ecology and prey relationships on Isle Royale. U.S. National Parks Service Monographs Series 11.

Phillips, R. L., W. E. Berg, and D. B. Siniff. 1973. Movement patterns and home range use of moose in northwestern Minnesota. Journal of Wildlife Management 37:266–278.

Pimlott, D. H. 1953. Newfoundland moose. Pages 563–579 *in* Trans. 18th North American Wildlife Conference.

Pimm, S. L., G. J. Russell, J. L. Gittleman, and T. M. Brooks. 1995. The Future of Biodiversity. Science 269:347-350.

Pinard, V., C. Dussault, J.-P. Ouellet, D. Fortin, and R. Courtois. 2012. Calving rate, calf survival rate, and habitat selection of forest-dwelling caribou in a highly managed landscape. Journal of Wildlife Management 76:189–199.

Pirnie, M. D. 1935. Michigan waterfowl management. Michigan Department of Conservation, Lansing, Michigan, USA.

Poole, K. G., R. Serrouya, and K. Stuart-Smith. 2007. Moose calving strategies in interior montane ecosystems. Journal of Mammalogy 88:139–150.

Porter, W. F. and H. B. Underwood. 1999. Of elephants and blind men: deer management in the U.S. National Parks. Ecological Applications 9:3-9.

Potvin, F., and N. Bertrand. 2004. Leaving forest strips in large clearcut landscapes of boreal forest: a management scenario suitable for wildlife? Forestry Chronicle 80:44–53.

Prescott, W. H. 1968. A study of winter concentration areas and food habits of moose in Nova Scotia. M.Sc. Thesis, Acadia University, Wolfville, Nova Scotia, Canada.

Proulx, G. 1982. Characteristics of moose (*Alces alces*) winter yards on different exposures and slopes in southern Quebec. Canadian Journal of Zoology 61:112–118.

Pulsifer, M. D., and T. Nette. 1995. History, status and present distribution of moose in Nova Scotia. Alces 31:209-219.

Ramankutty, N., and J. A. Foley. 1999. Estimating historical changes in global land cover: croplands from 1700 to 1992. Global Biogeochemical Cycles 13:997–1027.

R Development Core Team. 2014. R: A language and environment for statistical computing. Version 3.2.1. R Foundation for Statistical Computing, Vienna, Austria. http://www.r-project.org/. Accessed 18 November 2014.

Redmond, K. T. and J. T. Abatzoglou. 2014. Current Climate and Recent Trends. Pages 53–94 *in* G. Ohring, editor. Climate Change in North America, Regional Climate Studies, Springer International Publishing, Switzerland.

Reese, E. O. and C. T. Robbins. 1994. Characteristics of moose lactation and neonatal growth. Canadian Journal of Zoology 72:953–957.

Reeves, H. M., and R. E. McCabe. 2007. Of Moose and Man. Pages 1–76 *in* A.W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North America Moose. Second Edition. University Press of Colorado, Boulder, Colorado, USA.

Rempel, R. S., P. C. Elkie, A. R. Rodgers, and M. J. Gluck. 1997. Timber-management and natural-disturbance effects on moose habitat: landscape evaluation. Journal of Wildlife Management 61:517–524.

Renecker, L. A., and R. J. Hudson. 1986. Seasonal energy expenditures and thermoregulatory responses of moose. Canadian Journal of Zoology 64:322–327.

Renecker, L. A., and C.C. Schwartz. 1998. Food habits and feeding behaviour. In Ecology and Management of the North America Moose. Edited by A.W. Franzmann and C. C. Schwartz. Smithsonian Institution Press, Washington, D.C., USA.

Rettie, W. J. and P. D. McLoughlin. 1999. Overcoming radiotelemetry bias in habitat-selection studies. Canadian Journal of Zoology 77:1175–1184.

Ritcey, R. W. and N. A. M. Verbeek. 1969. Observations of moose feeding on aquatics in Bowron Lakes Park, B.C. Canadian Field-Naturalist 83:339–343.

Risenhoover, K. L. 1986. Winter activity patterns of moose in interior Alaska. Journal of Wildlife Management 50:727–734.

Rodgers, A. R., A. P. Carr, H. L. Beyer, L. Smith, and J. G. Kie. 2007. HRT: Home Range Tools for ArcGIS. Version 2.0. Ontario Ministry of Natural Resources and Forestry, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada. http://flash.lakeheadu.ca/~arodgers/hre/SRN-HRT.pdf and http://flash.lakeheadu.ca/~arodgers/hre/ Accessed 18 November 2014.

Roffe, T. J., K. Coffin, and J. Berger. 2001. Survival and immobilizing moose with carfentanil and xylazine. Wildlife Society Bulletin 29:1140–1146.

Roffe, T. J., S. J. Sweeney, and K. E. Aune. 2005. Chemical immobilization of North American mammals. Pages 286–302 *in* C. E. Braun, editor. Techniques for Wildlife Investigations and Management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA.

Rolley, R. E. and L. B. Keith. 1980. Moose population dynamics and winter habitat use at Rochester, Alberta, 1965–1969. Canadian Field-Naturalist 94:9–18.

Rooney, S., M.A. Wolfe, and T.J. Kayden. 1998. Autocorrelated data in telemetry studies: time to independence and the problem of behavioral effects. Mammal Review 28:89–98.

Rosenzweig, C., G. Casassa, D. J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T. L. Root, B. Seguin, and P. Tryjanowski. 2007. Assessment of observed changes and responses in natural and managed systems. Pages 79-131 *in* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, editors. Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.

Rouan, L., J-M. Gaillard, Y. Guédon, and R. Pradel. 2009. Estimation of Lifetime Reproductive Success When Reproductive Status Cannot Always Be Assessed. In: D. L. Thomson, E. G. Cooch, M. J. Conroy (eds). Modeling Demographic Processes in Marked Populations. Environmental and Ecological Statistics, vol 3. Springer, Boston, MA, USA.

Samson, F.B., F.L. Knopf, and W. Ostlie. 2004. Great Plains Ecosystems: Past, Present, and Future. Wildlife Society Bulletin 32:6-15.

Sandegren, F., R. Bergström, G. Cederlund, and E. Dansie. 1982. Spring migration of female moose in central Sweden. Alces 18:210–234.

Saskatchewan Crop Insurance Corporation (SCIC). 2019. Wildlife Damage. https://www.scic.ca/wildlife/. Accessed 29 November 2019.

Saskatchewan Ministry of Agriculture. 2003. Irrigation in Saskatchewan Version #3 (Revised May 2003). Saskatchewan Agriculture, Food and Rural Revitalization Irrigation Divisions of Crop Development Branch and Inspection and Regulatory Branch. http://www.agriculture.gov.sk.ca/Default.aspx?DN=59abfaba-401e-49fb-91d0-d357692288d4. Accessed 18 November 2014.

Saskatchewan Ministry of Environment. 2013. Saskatchewan Wildlife Management Report 2006–2011. Fish and Wildlife Technical Report 2013.

Saskatchewan Ministry of Environment. 2013. Special Permit: Research permit – Academic. Permit No. 13FW035.

Saskatchewan Ministry of Environment. 2014. Special Permit: Research permit – Academic. Permit No. 14FW054.

Saskatchewan Ministry of Environment. 2017. Saskatchewan Wildlife Management Report 2016. Fish and Wildlife Technical Report 2017-1. http://publications.gov.sk.ca/documents/66/104335-Saskatchewan%20Wildlife%20Management%20Report%20-%202016.pdf. Accessed 11 July 2018.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5:18-32.

Scarpitti, D. L., C. Habeck, A. R. Musante, and P. J. Pekins. 2005. Integrating habitat use and population dynamics of moose in northern New Hampshire. Alces 41:25–35

Schielzeth, H. 2010. Simple means to improve the interpretability of regression coefficients. Methods in Ecology and Evolution 1:103–113.

Schneider, R. R., and S. Wasel. 2000. The effect of human settlement on the density of moose in northern Alberta. Journal of Wildlife Management 64:513–520.

Schwab, F. E. 1985. Moose habitat selection in relation to forest cutting practices in northcentral British Columbia. Dissertation, University of British Columbia.

Schwartz, C. C., and A. W. Franzmann. 1989. Bears, wolves, moose, and forest succession, some management considerations on the Kenai Peninsula, Alaska. Alces 25:1–10.

Schwartz, C. C. 1992a. Physiological and nutritional adaptations of moose to northern environments. Alces Supplement 1:139–155.

Schwartz, C. C. 1992b. Techniques of moose husbandry. Alces Supplement 1:177–192.

Schwartz, C. C., and K. J. Hundertmark. 1993. Reproductive characteristics of Alaskan moose. Journal of Wildlife Management 57:454–468.

Schwartz, C. C. 2007. Reproduction, Natality, and Growth. Pages 141–171 *in* A.W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North America Moose. Second Edition. University Press of Colorado, Boulder, Colorado, USA.

Seiler, A. 2003. Effects of Infrastructure on Nature. Pages 31–50 *in* M. Trocmé, S. Cahill, J. G. De Vries, H. Farrall, L. Folkeson, G. Fry, C. Hicks, J. Peymen, editors. Habitat fragmentation due to transportation infrastructure: the European review. Office for Official Publications of the European Communities, Luxembourg.

Severinghaus, C. W. and E. L. Cheatum. 1956. Life and times of the white-tailed deer. Pages 57–186 *in* W. P. Taylor, editor. The deer of North America. Stackpole Company, Harrisburg, Pennsylvania, USA.

Shipley, L. A., S. Blomquist, and K. Danell. 1998. Diet choices made by free-ranging moose in northern Sweden in relation to plant distribution, chemistry, and morphology. Canadian Journal of Zoology 76:1722–1733.

Sielecki, L. E. 2007. Wildlife Accident Reporting System (WARS) 1988-2007 – Wildlife Accident Monitoring and Mitigation in British Columbia – Special Annual Report. Ministry of Transportation and Infrastructure, Victoria, British Columbia. http://www.th.gov.bc.ca/publications/eng_publications/environment/WARS_reports.htm. Accessed 11 July 2018.

Sigouin, D., J.-P. Ouellet, and R. Courtois. 1997. Geographical variation in the mating and calving periods of moose. Alces 33:85–95.

Snaith, T. V., and K. F. Beazley. 2004. The distribution, status and habitat associations of moose in mainland Nova Scotia. Proceedings of the Nova Scotia Institute of Science 42:263–317.

Sorensen, A. A., F. M. van Beest, and R. K. Brook. 2015. Quantifying overlap in crop selection patterns among three sympatric ungulates in an agricultural landscape. Basic and Applied Ecology 16:601–609.

Speed, J. D. M., G. Austrheim, A. J. Hester, E. J. Solberg, and J.-P. Tremblay. 2013. Regional-scale alteration of clear-cut forest regeneration caused by moose browsing. Forest Ecology and Management 289:289–299.

Stankowich, T. 2008. Ungulate flight responses to human disturbance: a review and meta-analysis. Biological Conservation 141:2159–2173.

Statistics Canada. 2011. 2011 Census of Agriculture. http://www.statcan.gc.ca/ca-ra2011/index-eng.htm. Accessed 27 September 2013.

Statistics Canada. 2012. Saskatoon, Saskatchewan (Code 4711066) and Division No. 11, Saskatchewan (Code 4711) (table). Census Profile. 2011 Census. Statistics Canada Catalogue no. 98-316-XWE. Ottawa. Released October 24, 2012. http://www12.statcan.gc.ca/census-recensement/2011/dp-pd/prof/index.cfm?Lang=E. Accessed 27 September 2013.

Stephens, P. W. and R. O. Peterson. 1984. Wolf-avoidance strategies of moose. Holarctic Ecology 7:239–244.

Stevens, D. R. 1970. Winter ecology of moose in the Gallatin Mountains, Montana. Journal of Wildlife Management 34:37–46.

Stewart, R. R., E. H. Kowal, R. Beaulieu, and T. W. Rock. 1985. The impact of black bear removal on moose calf survival in east-central Saskatchewan. Alces 21:403–418.

Stringham, S. F. 1974. Mother-infant relations in moose. Naturaliste Canadien 101:325–369.

Swihart, R. K. and N. A. Slade. 1985. Testing for independence of observations in animal movements. Ecology 66:1176–1184.

Tatman, N. M., W. B. Ballard, M. C. Wallace, S. P. Haskell, P. R. Krausman, J. DeVos Jr., and O. J. Alcumbrac. 2011. Evaluation of use of vaginal-implant transmitters in mule deer (*Odocoileus hemionus*). The Southwestern Naturalist 56:247–289.

Telfer, E. S. 1970. Winter habitat selection by moose and white-tailed deer. Journal of Wildlife Management 34:553–559.

Telfer, E. S. 1984. Circumpolar distribution and habitat requirements of moose (*Alces alces*). Pages 145–182 *in* R. Olson, R. Hastings, and F. Gedes, editors. Northern Ecology and Resource Management. University of Alberta Press, Edmonton, Alberta, Canada.

Telfer, E.S. 1995. Moose range under presettlement fire cycles and forest management regimes in the boreal forest of Western Canada. Alces 31:153–165.

Testa, J. W. and G. P. Adams. 1998. Body condition and adjustments to reproductive effort in female moose (*Alces alces*). Journal of Mammalogy 79:1345–1354.

Testa, J. W., E. F. Becker, and G. R. Lee. 2000a. Temporal patterns in the survival of twin and single moose (*Alces alces*) calves in southcentral Alaska. Journal of Mammalogy 81:162–168.

Testa, J. W., E. F. Becker, and G. R. Lee. 2000b. Movements of female moose in relation to birth and death of calves. Alces 36:155–162.

Testa, J. W. 2002. Does predation on neonates inherently select for earlier births? Journal of Mammalogy 83:699–706.

Thomas, D. L. and E. J. Taylor. 2006. Study designs and tests for comparing resource use and availability II. Journal of Wildlife Management 70:324–336.

Thompson, I. D., and M. F. Vukelich. 1981. Use of logged habitats in winter by moose cows with calves in northeastern Ontario. Canadian Journal of Zoology 59:2103–2114.

Timmerman, H. R. 2003. The status and management of moose in North America – circa 2000–01. Alces 39:131–151.

Tremblay, J.-P., E. J. Solberg, B.-E. Sæther, and M. Heim. 2007. Fidelity to calving areas in moose (*Alces alces*) in the absence of natural predators. Canadian Journal of Zoology 85:902–908.

U.S. Fish and Wildlife Service. 2011. Waterfowl population status, 2011. U.S. Department of the Interior, Washington, D.C., USA.

U.S. Fish and Wildlife Service. 2012. Waterfowl population status, 2012. U.S. Department of the Interior, Washington, D.C., USA.

U.S. Fish and Wildlife Service. 2013. Waterfowl population status, 2013. U.S. Department of the Interior, Washington, D.C., USA.

U.S. Fish and Wildlife Service. 2014. Waterfowl population status, 2014. U.S. Department of the Interior, Washington, D.C., USA.

U.S. Fish and Wildlife Service. 2015. Waterfowl population status, 2015. U.S. Department of the Interior, Washington, D.C., USA.

Van Auken, O.W. 2009. Causes and consequences of woody plant encroachment into western North American grasslands. Journal of Environmental Management 90: 2931–2942.

Van Dyke, F., B. L. Probert, and G. M. Van Beek. 1995. Seasonal habitat use characteristics of moose in south-central Montana. Alces 31:15–26.

Verbyla, D. 2011. Browning boreal forests of western North America. Environmental Research Letters 6, Article No. 041003.

VerCauteren, K. C., M. J. Lavelle, and S. Hygnstrom. 2006. From the field: fences and deer-management: a review of designs and efficacy. Wildlife Society Bulletin 34:191–200.

Wallgren, M., R. Bergström, G. Bergqvist, and M. Olsson. 2013. Spatial distribution of browsing and tree damage by moose in young pine forests, with implications for the forest industry. Forest Ecology and Management 305:229–238.

Wam, H. K., and O. Hjeljord. 2010. Moose summer and winter diets along a large scale gradient of forage availability in southern Norway. European Journal of Wildlife Research 56:745–755.

Warren, R., J. Price, A. Fischlin, S. de la Nava Santos, and G. Midgley. 2011. Increasing impacts of climate change upon ecosystems with increasing global mean temperature rise. Climatic Change 106:141–177.

Water Security Agency. 2019. Agricultural Water Management Strategy. https://www.wsask.ca/Water-Programs/Agricultural-Drainage-/Agricultural-Water-Management-Strategy/. Accessed 29 November 2019.

Wattles, D. W. and S. DeStefano. 2013. Moose habitat in Massachusetts: assessing use at the southern edge of the range. Alces 49:133–147.

Webster, S. M. 1999. Interpreting Northern Plains Subsistence Practices: An Analysis of the Faunal and Floral Assemblages from the Thundercloud Site (FbNp-25). M.A. Thesis, Department of Anthropology and Archaeology. University of Saskatchewan, Saskatoon, Canada.

Weisberg, P. J. and H. Bugmann. 2003. Forest dynamics and ungulate herbivory: from leaf to landscape. Forest Ecology and Management 181:1–12.

Welch, I. D., A. R. Rodgers, and R. S. McKinley. 2000. Timber harvest and calving site fidelity of moose in northwestern Ontario. Alces 36:93–103.

White, K. S. and J. Berger. 2001. Antipredator strategies of Alaskan moose: are maternal trade-offs influenced by offspring activity? Canadian Journal of Zoology 79:2055–2062.

White, G. C. and R. A. Garrott. 1990. Analysis of wildlife radio-tracking data. Academic Press, San Diego, California, USA.

White, M., F. F. Knowlton, and W. C. Glazener. 1972. Effects of dam-newborn fawn behavior on capture and mortality. Journal of Wildlife Management 36:897–906.

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying Threats to Imperiled Species in the United States. BioScience 48:607–615.

Wildlife Management Institute. 2014. States Initiating Research on Moose Declines; Minnesota Halts Hunt. Outdoor News Bulletin. https://www.wildlifemanagementinstitute.org/index.php?option=com_content&view=article&id=643:states-initiating-research-on-moose-declines&catid=34:ONB%2520Articles&Itemid=54. Accessed 6 April 2016.

Wilson, E.O. 1992. The Diversity of Life. Belknap Press, Cambridge, MA, USA.

Woodroffe, R., and J. R. Ginsberg. 1998. Edge effects and the extinction of populations inside protected areas. Science 280:2126–2128.

Worton, B. J. 1987. A review of models of home range for animal movement. Ecological Modelling 38:277–298.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164–168.

Worton, B. J. 1995. Using monte carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59:794–800.